UNIVERSITÉ DE MONTRÉAL

NEUTRONICS-THERMALHYDRAULICS COUPLING IN A CANDU SCWR

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NEUTRONICS-THERMALHYDRAULICS COUPLING IN A CANDU SCWR

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RÉSUMÉ

Le but de ce travail est de déterminer la distribution de puissance et les paramètres thermohydrauliques pour un réacteur CANDU SCWR, par un couplage neutronique-thermohydraulique. La distribution de puissance obtenue a un facteur de puissance de 1.4. Chaque canal a un maximum de puissance à la troisième grappe (à partir de l'entrée du canal), et cette valeur maximale augmente avec la puissance du canal. Le coéfficient de transfère thermique et la chaleure spécifique atteingnent leur valeur maximale à la même position dans un canal, et cette position se déplace vers l'entrée du canal en raison d'une augmentation de puissance de canal. La température de sortie du caloporteur augmente avec la puissance du canal, tandis que la préssion et la densité de sortie diminuent avec l'augmentation de la puissance du canal. L'augmentation de la puissance du canal résulte aussi en des températures élevées pour le combustible et la gaine. Le facteur de multiplication et les paramêtres thermohydrauliques oscillent autours de leurs valeurs à la convergence.

ABSTRACT

In order to implement new nuclear technologies as a solution to the growing demand for energy, 10 countries agreed on a framework for international cooperation in 2002, to form the Generation IV International Forum (GIF). The goal of the GIF is to design the next generation of nuclear reactors that would be cost effective and would enhance safety. This forum has proposed several types of Generation IV reactors including the Supercritical Water-Cooled Reactor (SCWR). The SCWR comes in two main configurations: pressure vessel SCWR and pressure tube SCWR (PT-SCWR). In this study, the CANDU SCWR (a PT-SCWR) is considered. This reactor is oriented vertically and contains 336 channels with a length of 5 m. The target coolant inlet and outlet temperatures are 350 Celsius and 625 Celsius, respectively. The coolant flows downwards, and the reactor power is 2540 MWth. Various fuel designs have been considered in order not to exceed the linear element rating. However, the dependency between the core power and thermalhydraulics parameters results in the necessity to use a neutronics/thermalhydaulics coupling scheme to determine the core power and the thermalhydraulics parameters. The core power obtained has a power peaking factor of 1.4. The bundle power distribution for all channels has a peak at the third bundle from the inlet, but the value of this peak increases with the channel power. The heat-transfer coefficient and the specific-heat capacity have a peak at the same location in a channel, and this location shifts toward the inlet as the channel power increases. The exit coolant temperature increases with the channel power, while the exit coolant density and pressure decrease with the channel power. Also, higher channel powers lead to higher fuel and cladding temperatures. Moreover, as the coupling method is applied, the effective multiplication factor and the values of thermalhydaulics parameters oscillate as they converge.

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LIST OF ACRONYMS AND ABREVIATIONS

P	Power
$\dot{m}$	Mass flow rate
q''	Heat flux
q'''	Power density
Q_1	Heat transfer rate from fuel to cladding
Q_2	Heat transfer rate from cladding to coolant
V_f	Fuel volume
V_g	Cladding volume
A_f	Fuel surface area
A_g	Cladding surface area
h_c	Coolant heat transfer coefficient
h_{gap}	Gap conductance between fuel and cladding
H	Enthalpy
c_p	Specific-heat capacity of the coolant
N_{rod}	Number of fuel rods per bundle
R_{rod}	Radius of each fuel rod
k_c	Coolant thermal conductivity
G	Mass flux
f	Single-phase friction factor
t_f	Fuel temperature
t_g	Cladding temperature
ρ_c	Coolant density
K_{eff}	Effective multiplication factor
p	Coolant pressure
AECL	Atomic Energy of Canada Limited
$\nu\Sigma_f$	Product of the macroscopic fission cross section to the average number of neutrons produced by fission
Σ	Total macroscopic fission cross section
D_h	Hydraulic diameter
P_{wet}	Wetted perimeter
D_{he}	Heated equivalent diameter
P_{he}	Heated perimeter
n_{R1}	Number of fuel elements in Ring 1
Nu	Nusselt number
Re	Reynolds number

Pr	Prandtl number
n_{R2}	Number of fuel elements in Ring 2
n_{R3}	Number of fuel elements in Ring 3
D_c	Diameter of central pin including cladding
D_{R1}	Outer diameter of pins in Ring 1
D_{R2}	Outer diameter of pins in Ring 2
D_{R3}	Outer diameter of pins in Ring 3
D_{liner}	Inner diameter of liner
A_{flow}	Flow area
μ	Dynamic viscosity
c_{pf}	Specific heat-capacity of the fuel
c_{pg}	Specific heat-capacity of the cladding
PWR	Pressurized-water reactor

INTRODUCTION

In order to implement new nuclear technologies as a solution to the growing demand for energy, 10 countries agreed on a framework for international cooperation in 2002, to form the Generation IV International Forum (GIF). The goal of the GIF is to design the next generation of nuclear reactors that would be cost effective and would enhance safety. This forum has proposed several types of Generation IV reactors including the Supercritical Water-Cooled Reactor (SCWR). The SCWR comes in two main configurations: pressure vessel SCWR and pressure tube SCWR (PT-SCWR).

Several neutronics/thermalhydaulics coupling studies have been performed on the CANDU SCWR (a PT-SCWR) to understand its properties. Shan *et al.* (2009a) studied the effects of fuel enrichment and of the lattice pitch on the power distribution within a channel. The channel consisted of the 43-rod CANFLEX bundle, and the coupling was done through MCNP (Briesmeister, 2000) and ATHAS (Shan *et al.*, 2009b). To analyze the effects of fuel enrichment, two cases were considered: a reference case and an improved case. In the reference case, all fuel rods were assumed to be made of UO_2 enriched to 4% in U235. The results showed that, for each fuel bundle, the power was not evenly distributed across all sub-channels, with the power peak located next to the outer sub-channels. Also, the heat-transfer coefficient was relatively low around this region. Therefore, the cladding temperatures in some outer sub-channels exceeded the allowed cladding temperature. To solve this problem, Shan *et al.* (2009a) proposed an improved case in which the fuel rods in rings 1, 2, 3, and 4 would be enriched to 6%, 6%, 5%, and 2.5%, respectively. As a result, the radial power in each bundle was more evenly distributed, and the cladding temperatures were within the allowable limit. They concluded the study by showing that lower values of the lattice pitch resulted in a more uniform radial power distribution in a channel.

The 43-rod CANFLEX bundle was intended to be used in a horizontal CANDU SCWR, similar to a CANDU 6 reactor, with online refueling. However, it was determined that online refueling was not an easy option with supercritical water. Consequently, high-burnup bundle designs were considered so as not to use online refueling and to allow longer refueling cycles. Nevertheless, the use of high-burnup fuel imposed severe contraints on the linear element rating (LER) due to the accumulation of fission gases between the fuel and the cladding, as the fuel is irradiated (MacDonald *et al.*, 2011). MacDonald *et al.* (2011) performed a neutronics/thermalhydaulics coupling study to calculate the linear element rating for three bundle designs. The first one was the 54-element-bundle design that consisted of one non-fuel rod in the center surrounded by 54 fuel rods arranged in 3 rings of 12, 18, and 24 rods, respectively.

Also, the design used fuel rods of the same diameter. The second design had 79 rods per bundle, out of which only the central pin did not contain fuel. The central pin in this case was surrounded by 3 rings of 15, 21, and 42 elements, respectively. The fuel rods in the outer ring had a smaller diameter in order to reduce their LER. As Shan *et al.* (2009a) had shown, the fuel rod in the outer ring would generate the maximum power in the bundle. Therefore, it would be important to impose a restriction on their diameter to insure their LER had an acceptable value. The third design had 51 rods with one non-fuel rod at the center and 50 fuel rods arranged in 3 rings of 12, 18, and 20 rods, respectively. Once again, the focus in this design was on the outer ring. This design would reduce the LER in this ring by using fuel rods with an annular shape (having a hole at the center in which the coolant flows) In all three designs, a homogeneous fuel composition of Thorium Oxyde with 12% Plutonium Oxyde was considered. MacDonald *et al.* (2011) concluded that the 79-rod design gave the lowest LER for a burnup of up to 40MWD/Kg.

It this study, the vertically-oriented CANDU SCWR is analyzed. It contains 336 channels with a length of 5 m. The target coolant inlet and outlet temperatures are 350 C and 625 C, respectively. The coolant flows downwards at a pressure above the critical pressure, and the reactor power is 2540 MWth.

The aim of this study is to use the neutronics-thermalhydraulics coupling method to determine the core-power distribtution and the thermalhydraulics parameters of a CANDU SCWR. To this end, Chapter 1 gives a description of the SCWR-cell model and of the reactor-database generation process. Chapter 2 presents the reactor-core model, the steady-state thermalhydraulics and heat-transfer models, and the coupling algorithm. In Chapter 3, the results obtained for selected channels are conveyed. Finally, a discussion of the significance of the results concludes the study.

CHAPTER 1

CANDU SCWR CELL AND REACTOR DATABASE

The implementation of a neutronics/thermalhydraulics coupling scheme relies on the use of a reactor-cell model to generate the cross-section database for full-core calculations. The cell model also gives information about the dependence of the effective multiplicative factor on local and global parameters. This chapter gives a description of the cell model, analyzes the effects of local parameters (fuel temperature, coolant temperature, and coolant density) on the effective multiplication factor, and gives details about the reactor-database generation process.

1.1 Cell-model description

The reactor-cell model used is presented in Figure 1.1, and its parameters are given in Table 1.1 (Pencer, 2008). It has 54 fuel rods organized in 3 rings having 12, 18, and 24 elements, respectively. The center pin contains light water surrounded by cladding. Table 1.2 gives details about its composition (Pencer, 2008); in this table, the isotopic content of the PuO2 is 2.5%, 54.2%, 23.8%, 12.6%, and 6.8% in Pu238, Pu239, Pu240, Pu241, and Pu242, respectively.

The CANDU SCWR cell differs from the CANDU 6 cell in many aspects. The CANDU SCWR cell has more fuel rods per bundle, and uses an insulator and a liner to seperate the pressure tube from the coolant. The insulator is used to prevent damage to the pressure tube resulting from the high-temperature coolant, and the liner protects the insulator from being damaged during channel refueling. The CANDU SCWR cell also has a central pin whose goal is to reduce the coolant-void reactivity. Due to the presence of the high-temperature coolant, the cladding is made of stainless steel, instead of Zirconium.

1.2 Cell neutronics properties

The multigroup transport equation is given by (Hébert, 2008)

$$\Omega \cdot \nabla \phi_g(\mathbf{r}, \Omega) + \Sigma_g(\mathbf{r}) \phi_g(\mathbf{r}, \Omega) = Q_g(\mathbf{r}, \Omega) \tag{1.1}$$

Table 1.1 CANDU SCWR channel parameters

Parameter	Value	Parameter	Value
Pitch circle radius, ring 1	2.8755 cm	Lattice pitch	25 cm
Pitch circle radius, ring 2	4.3305 cm	Pressure tube inner radius	8.23 cm
Pitch circle radius, ring 3	5.8000 cm	Pressure tube thickness	1.4 cm
Radius of central pin	1.8 cm	Liner tube inner radius	6.8 cm
Outer radius of central pin cladding	2.0 cm	Liner tube thickness	0.1 cm
Radius of pins in ring 1, 2 and 3	0.620 cm	Insulator inner radius	6.9 cm
Outer radius of ring 1, 2 and 3 pin cladding	0.660 cm	Insulator thickness	1.33 cm

Table 1.2 Cell composition

Material	Composition
Fuel rods	88 wt% ThO2, 12 wt% PuO2
Cladding (center pin and rings 1, 2, and 3)	310 Stainless Steel
Liner	30% 310 Stainless Steel, 70% Coolant
Insulator	30% ZrO2, 70% Coolant
Pressure tube	Zr-2.5Nb
Coolant	H2O
Moderator	D2O
Center pin	99.984% H2O, 0.0156% D2O

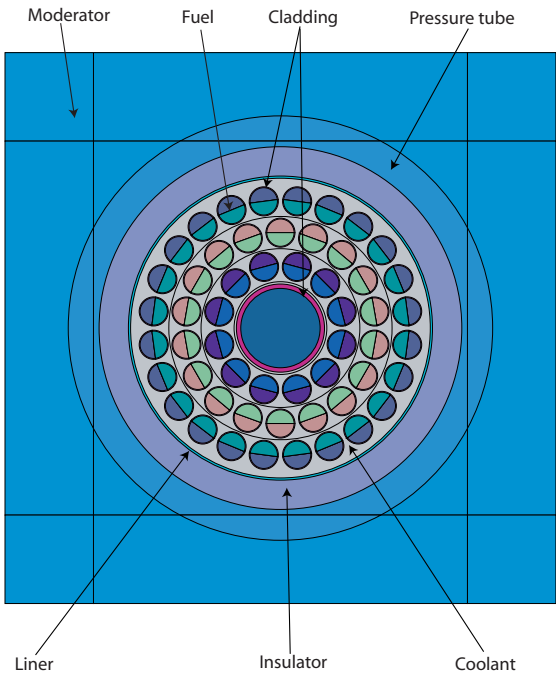


Figure 1.1 CANDU SCWR cell with 54 fuel elements per bundle

where $1 \leq g \leq G$,
and

$$Q_g(\mathbf{r},\Omega) = \sum_{h=1}^{G}\sum_{l=0}^{L}\frac{2l+1}{4\pi}\Sigma_{s,l,g\leftarrow h}(\mathbf{r})\sum_{m=-l}^{l}R_l^m(\Omega)\phi_{l,h}^m(\mathbf{r}) + \frac{1}{4\pi K_{eff}}\sum_{j=1}^{J}\chi_{j,g}\sum_{h=1}^{G}\nu\Sigma_{f,j,h}(\mathbf{r})\phi_h(\mathbf{r}) \quad (1.2)$$

$$\chi_{j,g} = \int_{u_{g-1}}^{u_g}\chi_j(u)du \quad (1.3)$$

In order to determine the properties of the CANDU SCWR cell and to generate the cross-section database required in subsequent full-core calculations, the version 3.06K of the DRAGON code is used (Marleau *et al.*, 2008). The multigroup transport equation is solved (with the assumption of isotropic scattering) by the method of collision probability, using the ENDF/B-VII nuclear library. A coarse geometry is used for self-shielding calculations, and a fine-mesh geometry is chosen for flux calculations (Figure 1.2). The flux obtained is used to homogenize cross sections over the entire cell and to condense them into 2 energy groups with a boundary of 0.625 eV (Harrisson and Marleau, 2011).

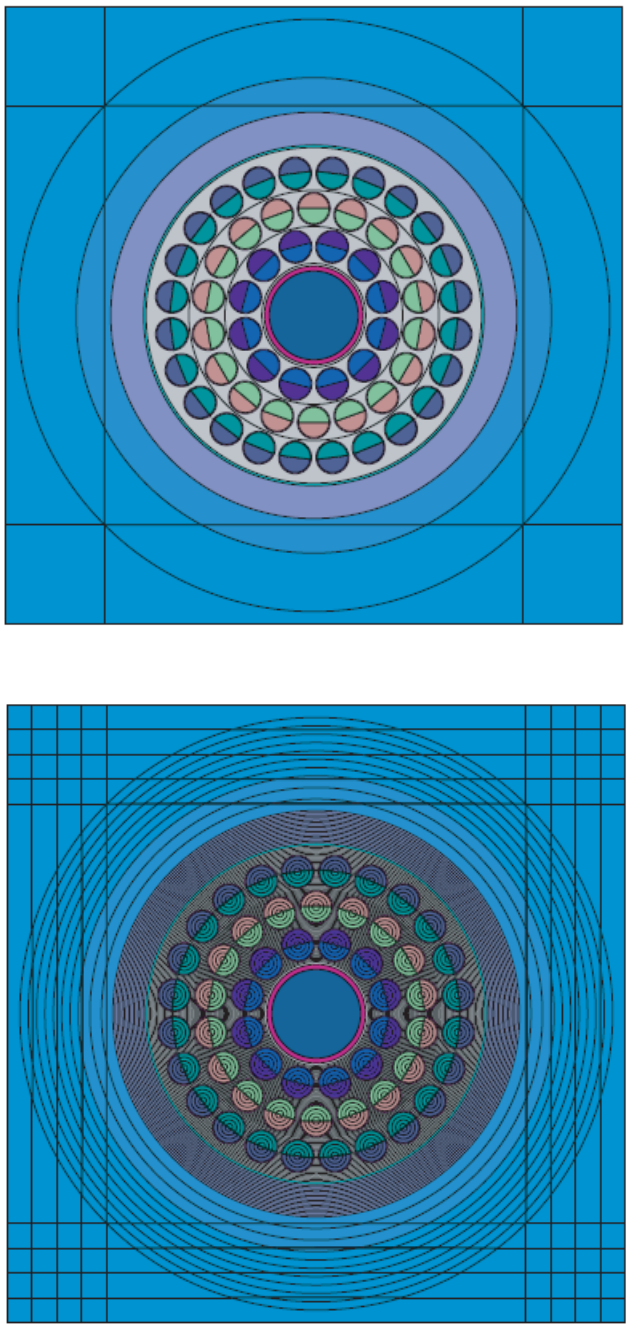


Figure 1.2 Cell model for self-shielding (top) and flux (bottom) calculations

1.2.1 Effect of burnup on reactivity

A lattice calculation (Figure 1.3) is done to analyse the impact of burnup on reactivity. The GEO: module defines two geometries (Figure 1.2). The NXT: module creates integration lines in both geometries. The LIB: module creates a microlib data structure that contains both microscopic and macroscopic cross sections for all reactions types and for all the isotopes considered. The microlib is generated based on the parameters given in Table 1.3. The SHI: module then performs resonance self-shielding calculations on the microlib, by using the coarse geometry. The collision probability matrices are calculated by the ASM: module, based on the self-shielded cross sections and the fine geometry. Once the collision probability matrices are known, the FLU: module determines the flux, along with the K_{eff}, and the EDI: module uses the flux to homogenize cross sections, over the entire cell, and to condense them into two energy groups. By using the specified bundle power and time step, the EVO: module solves the isotope evolution equations to determine their new concentrations; the new concentrations are added to the microlib. If the final simulation time is reached, the END: module terminates the DRAGON program; otherwise, the SHI: module performs self-shielding calculations on the new microlib data structure, and the computations continue according to Figure 1.3.

Once the K_{eff} is known, the reactivity ρ_{mk} is given by

$$\rho_{mk} = \frac{(K_{eff} - 1) \cdot 1000}{K_{eff}} \tag{1.4}$$

In Figure 1.4, the reactivity starts at 149.1 mk with fresh fuel and decreases with time due to

Table 1.3 Reference database parameters

Fuel temperature (K)	1273.15	Moderator purity (%)	99.833
Coolant temperature (K)	923.15	Boron concentration (cm· b)$^{-1}$	1.0E-10
Moderator temperature (K)	342.16	Xenon concentration (cm· b)$^{-1}$	1.0E-24
Coolant density (g· cm^{-3})	0.35	Samarium concentration(cm· b)$^{-1}$	1.0E-24
Moderator density (g· cm^{-3})	1.08509	Neptunium concentration (cm· b)$^{-1}$	1.0E-24
Coolant purity (%)	0.0156	Bundle power (MW)	0.75595

burnup. The reactivity is not less than 0 for burnup values up to approximately 25 MWD/Kg.

In the following sections, the effects of the fuel temperature, the coolant temperature, and the

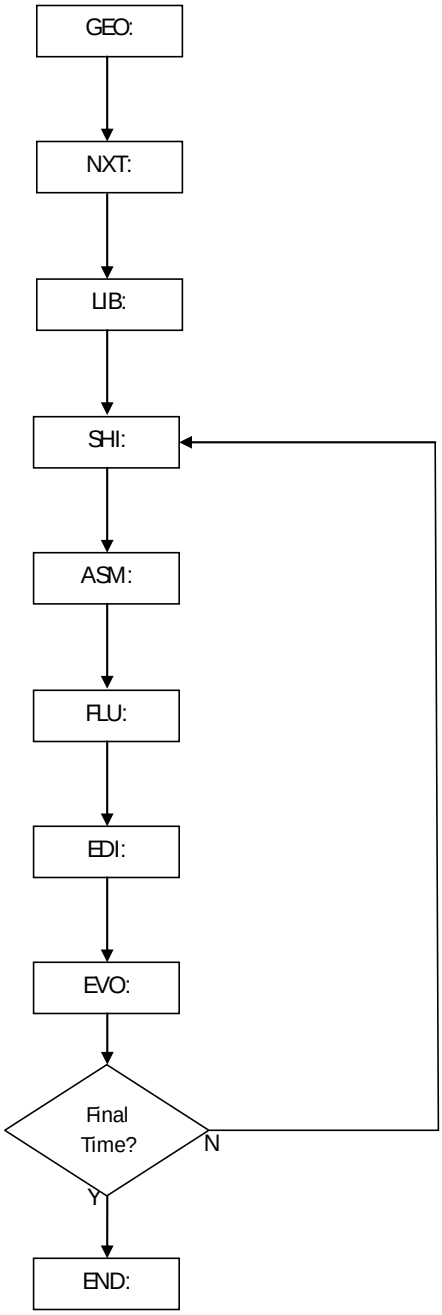


Figure 1.3 Calculation scheme for the effective multiplication factor

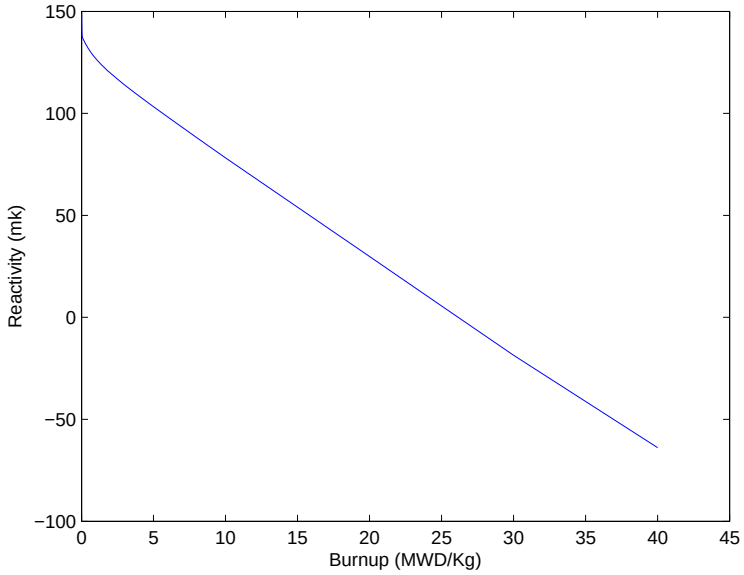


Figure 1.4 Reactivity as a function of burnup

coolant density on reactivity, are presented. In each case, the calculation scheme of Figure 1.3 is used, and only the parameter being analyzed (fuel temperature, coolant temperature, or coolant density) is varied, while all the other local and global parameters are kept at their reference values (Table 1.3). However, in all cases, the burnup is allowed to vary.

1.2.2 Effect of the fuel temperature on reactivity

The reactivity decreases with an increase in the fuel temperature due to the doppler effect (Figures 1.5). However, the fuel-temperature coefficient increases with burnup. The average fuel-temperature coefficients are -2.0602 mk/K, -1.8952 mk/K, and -1.6589 mk/K for 0 MWD/Kg, 15 MWD/Kg, and 25 MWD/Kg, respectively. These values are calculated from Figure 1.5 by the expression $\frac{\Delta\rho_{mk}}{\Delta t_f}$. The fuel-temperature coefficient decreases with the burnup probably because of the creation of U233 from Th232, and the fission cross section of U233 may counter the doppler effect.

1.2.3 Effect of the coolant temperature on reactivity

The coolant-temperature coefficient decreases with an increase in the coolant temperature. Also the sign of the coolant-temperature coefficient changes, but the temperature at which this transition occurs depends on the burnup (Figures 1.6). The change in the sign of the

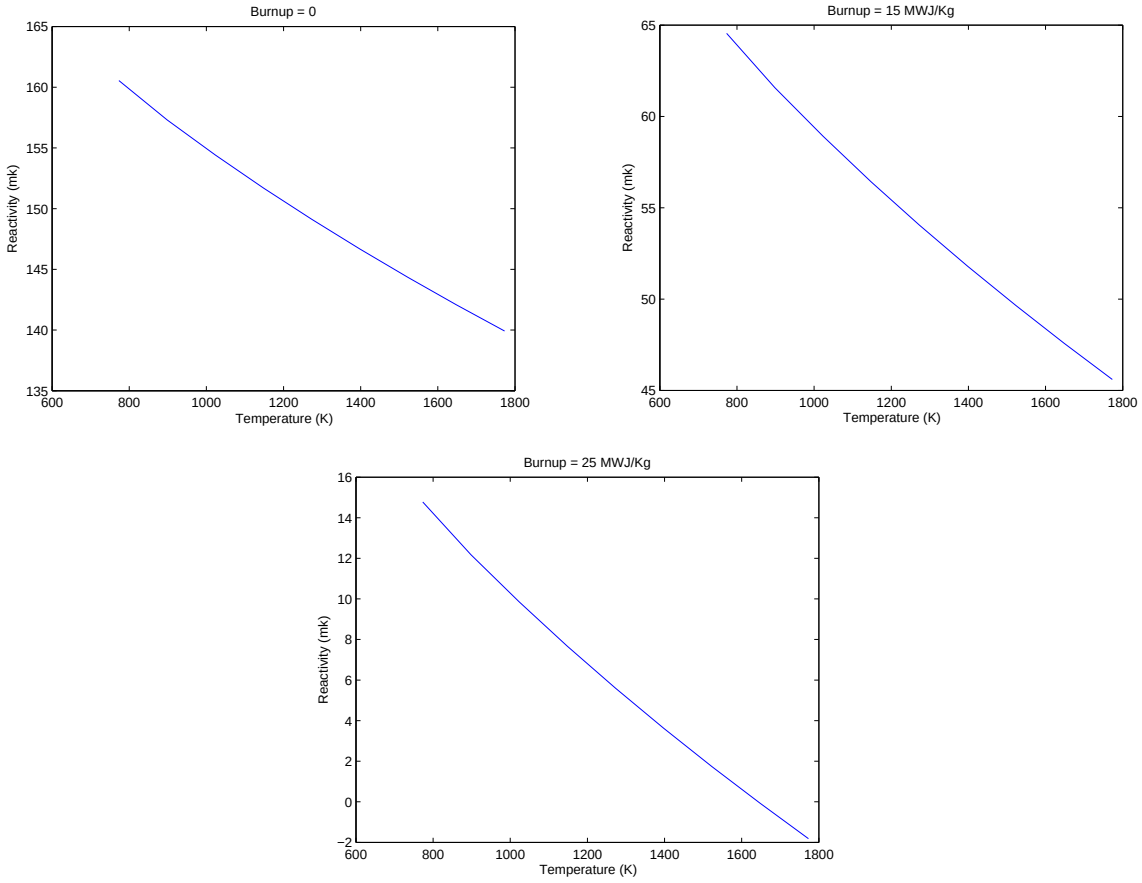


Figure 1.5 Effect of the fuel temperature on reactivity

coolant-temperature coefficient could be the result of peaks in the fission cross sections of Pu239 and U233 at 0.3 eV and 200 keV, respectively. Increasing the coolant temperature increases the energy of neutrons, and some of them have energy transitions past these resonance energies. For fresh fuel, the resonance of Pu239 is the main contributor. As the fuel burnup increases, more U233 is created and less Pu239 is present; therefore, U233 becomes more significant, and the transition temperature for the coolant-temperature coefficient increases. For fresh fuel, the transition happens at T = 412.5 K, whereas for 15 MWD/Kg and 25 MWD/Kg the transition temperatures are T = 637.5K and T = 862.5K, respectively.

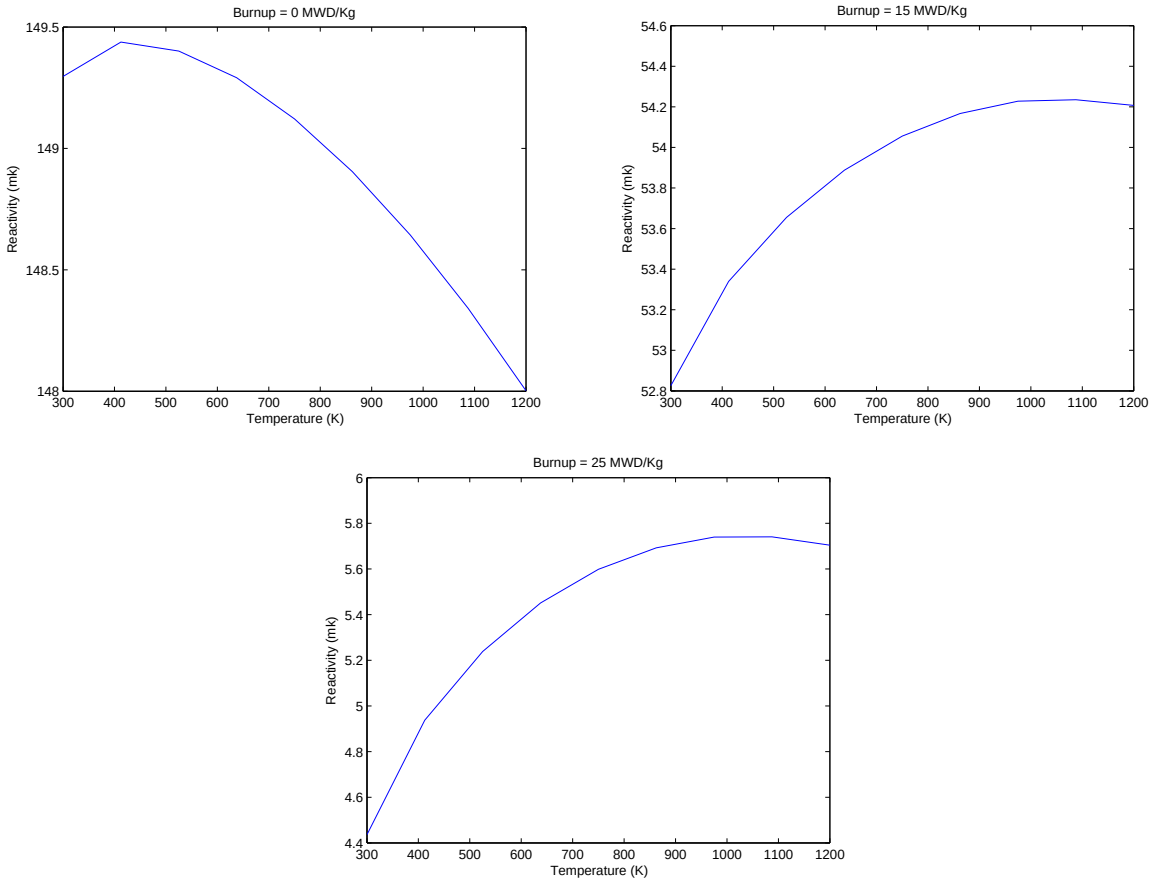


Figure 1.6 Effect of the coolant temperature on reactivity

1.2.4 Effect of the coolant density on reactivity

The coolant-density coefficient increases with an increase in the coolant density. Also the sign of the coolant-density coefficient changes, but the density at which this transition occurs does not depend on the burnup (Figures 1.7): the transition density in all three cases is determined to be $\rho_c = 0.0875$ g/cm^3. For densities $\rho_c \geq \rho_{ref}$, the calculated values of the coolant density coefficients are 39.4 mk/g·cm^3, 47.4 mk/g·cm^3, and 45.1 mk/g·cm^3 for 0 MWD/Kg, 15 MWD/Kg, and 25 MWD/Kg, respectively. In this case, the coolant-density coefficients are the values of $\frac{\Delta\rho_{mk}}{\Delta t_c}$, calculated from Figure 1.7. Moreover, the coolant void fraction is negative since
$\rho_{mk}(\rho_c = 10^{-3}$ g/cm^3) - $\rho_{mk}(\rho_c) < 0 \quad \forall \rho_c$ such that $\rho_c \geq \rho_{ref}$, where ρ_{ref} is the reference coolant density given in Table 1.3.

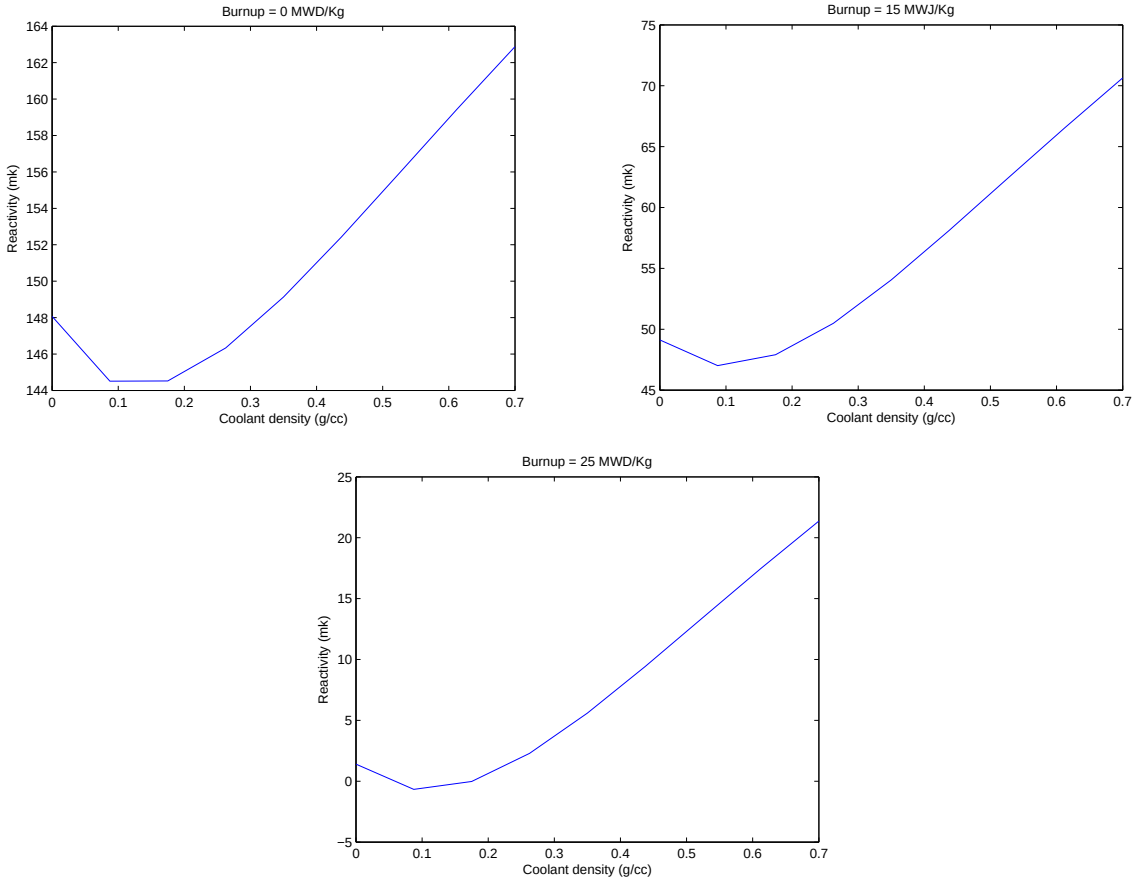


Figure 1.7 Effect of the coolant density on reactivity

1.3 Reactor-database generation

The generation of a reactor database can be done in three stages.
The first stage consists of creating a fixed-parameter database with each parameter fixed at its reference value (Table 1.3). More fixed-parameter databases are created during the second stage with the use of perturbation values (Table 1.4). It is worth mentioning that in the first two stages, the computations are performed according to Figure 1.8; this is similar to Figure 1.3, with the exception that the CPO: module is used to generate the databases. Finally, in the last stage, the CFC: module combines all the databases, resulting from the first two stages, into a single variable-parameter database for full-core calculations (Figure 1.9).

Table 1.4 Perturbation database parameters

Boron concentration (cm· b)$^{-1}$	0.0		
Coolant density (g· cm^{-3})	1.0E-4	0.7	
Moderator density (g· cm^{-3})	0.8	1.02	
Xenon concentration (cm· b)$^{-1}$	2.0E-9		
Samarium concentration (cm· b)$^{-1}$	7.0E-8		
Neptunium concentration (cm· b)$^{-1}$	3.0E-12		
Moderator purity (%)	98.5		
Coolant temperature (K)	573.15	1473.15	
Fuel temperature (K)	773.15	1773.15	
Moderator temperature (K)	292.16	372.16	
Bundle power (MW)	0.03	0.5	2

The database parameters are not all determined in the same way:

- The Boron concentrations are selected to agree with the fact that no Boron will be used in core calculations.
- The Xenon, Samarium, and Neptunium concentrations are determined through a lattice calculation that determines their maximum values during the reactor operating cycle, as indicated in Figure 1.10.
- The maximum and minimum values of the bundle power, fuel temperature, coolant temperature, and coolant density are selected so that their values in the core, obtained with the neutronics/thermalhydraulic coupling, are within these boundaries: these values are selected so that they represent upper/lower bounds for the bundle power, fuel temperature, coolant temperature, and coolant density values obtained with the neutronics/thermalhydraulics coupling to be discussed in the next chapter.

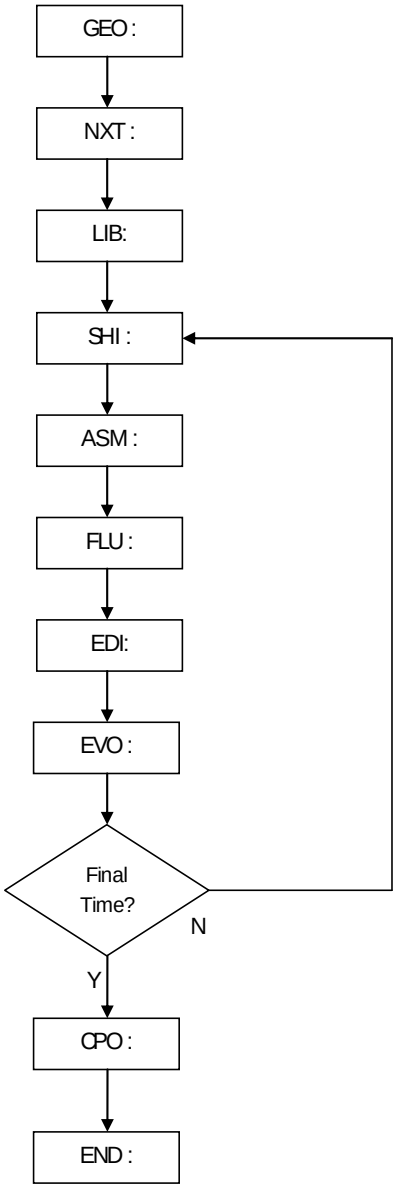


Figure 1.8 Calculation scheme for the generation of a fixed parameter database

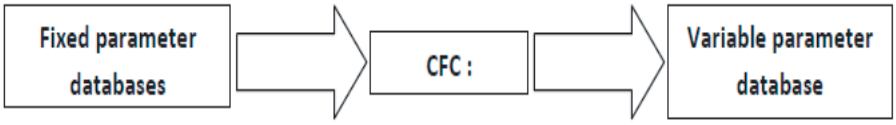


Figure 1.9 Calculation scheme for the generation of a variable-parameter database

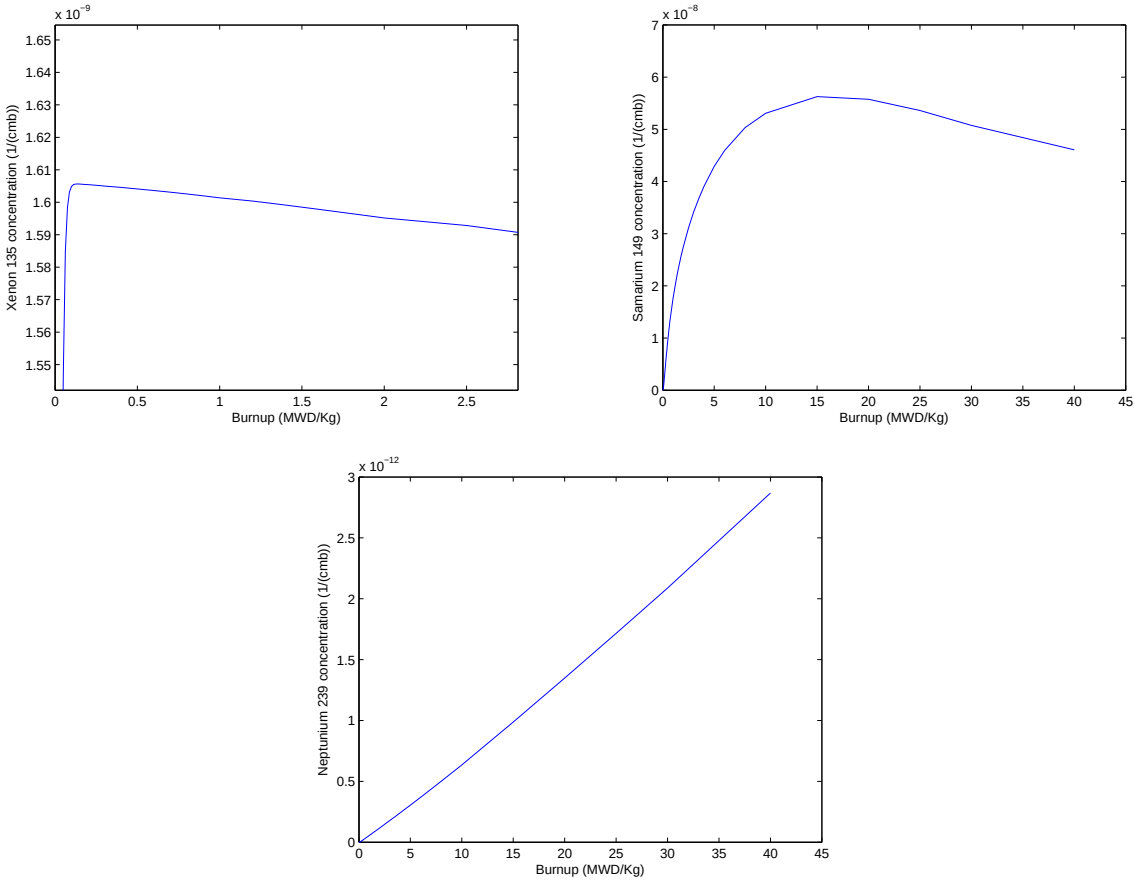


Figure 1.10 Variations of Xenon, Samarium, and Neptunium concentrations with burnup

1.4 Reactor-database validation

In order to validate the reactor database, a comparison between the macroscopic cross sections obtained with DRAGON and DONJON (Varin *et al.*, 2005) are compared. Different simulation conditions are selected, corresponding to reference conditions or perturbation conditions. The DRAGON macroscopic cross section data is generated by the CPO: module, while the DONJON macroscopic cross section data is generated by the AFM: module. The results show a very good agreement between the cross sections resulting from DRAGON and DONJON (Tables 1.5 and 1.6). To determine the difference in channel power resulting from the use of the CPO: and the AFM: cross sections, the core power is calculated under the following conditions:

- Simulation condition 1: $t_f = 1273.15$ K, $t_c = 923.15$ K, $\rho_c = 0.0001$ g$\cdot$ cm^{-3}
- Simulation condition 2: $t_f = 1273.15$ K, $t_c = 923.15$ K, $\rho_c = 0.7$ g$\cdot$ cm^{-3}

Table 1.5 Database validation (Part 1)

t_f = 1273.15 K, t_c = 923.15 K, ρ_c = 0.35 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.51377200E-03	2.48000638E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.51373220E-03	2.48006161E-02
Σ DRAGON (cm^{-1})	3.21466444E-01	4.39010563E-01
Σ DONJON (cm^{-1})	3.21468766E-01	4.39028349E-01
t_f = 773.15, t_c = 923.15, ρ_c = 0.35 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.55445641E-03	2.48937283E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.55441698E-03	2.48941645E-02
Σ DRAGON (cm^{-1})	3.21479797E-01	4.39049253E-01
Σ DONJON (cm^{-1})	3.21482064E-01	4.39066840E-01
t_f = 1773.15 K, t_c = 923.15 K, ρ_c = 0.35 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.48129926E-03	2.47234049E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.48126598E-03	2.47239291E-02
Σ DRAGON (cm^{-1})	3.21459742E-01	4.38978696E-01
Σ DONJON (cm^{-1})	3.21462169E-01	4.38996444E-01
t_f = 1273.15 K, t_c = 573.15 K, ρ_c = 0.35 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.50985294E-03	2.51425564E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.50981379E-03	2.51429933E-02
Σ DRAGON (cm^{-1})	3.21415968E-01	4.40689352E-01
Σ DONJON (cm^{-1})	3.21418334E-01	4.40707863E-01
t_f = 1273.15 K, t_c = 1473.15 K, ρ_c = 0.35 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.52269837E-03	2.42521590E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.52265855E-03	2.42525829E-02
Σ DRAGON (cm^{-1})	3.21576430E-01	4.37182931E-01
Σ DONJON (cm^{-1})	3.21578734E-01	4.37199693E-01

Table 1.6 Database validation (Part 2)

t_f = 1273.15 K, t_c = 923.15 K, ρ_c = 0.0001 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	3.80233530E-03	2.57132040E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	3.66699745E-03	2.59954415E-02
Σ DRAGON (cm^{-1})	2.82237007E-01	4.14263243E-01
Σ DONJON (cm^{-1})	2.75949165E-01	4.04561347E-01
t_f = 1273.15 K, t_c = 923.15 K, ρ_c = 0.7 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.88468069E-03	2.55906676E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.91055898E-03	2.58561428E-02
Σ DRAGON (cm^{-1})	3.60683613E-01	4.72757666E-01
Σ DONJON (cm^{-1})	3.66969935E-01	4.85383192E-01
t_f = 528.501 K, t_c = 416.3884 K, ρ_c = 0.264086 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.44213714E-03	2.53161277E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.41257098E-03	2.52200373E-02
Σ DRAGON (cm^{-1})	3.11764035E-01	4.34029735E-01
Σ DONJON (cm^{-1})	3.10630768E-01	4.36999036E-01
t_f = 1028.5 K, t_c = 805.0995 K, ρ_c = 0.1938247 g· cm^{-3}	Group 1	Group 2
$\nu\Sigma_f$ DRAGON (cm^{-1})	4.26642017E-03	2.49514516E-02
$\nu\Sigma_f$ DONJON (cm^{-1})	4.20798628E-03	2.51534902E-02
Σ DRAGON (cm^{-1})	3.03934086E-01	4.27176837E-01
Σ DONJON (cm^{-1})	3.01729445E-01	4.32215285E-01

In Figure 1.11, the maximum error occurs at outer channels, and has a value of 3.5% of the channel power where it occurs; the power of this channel is 3.02 MW.

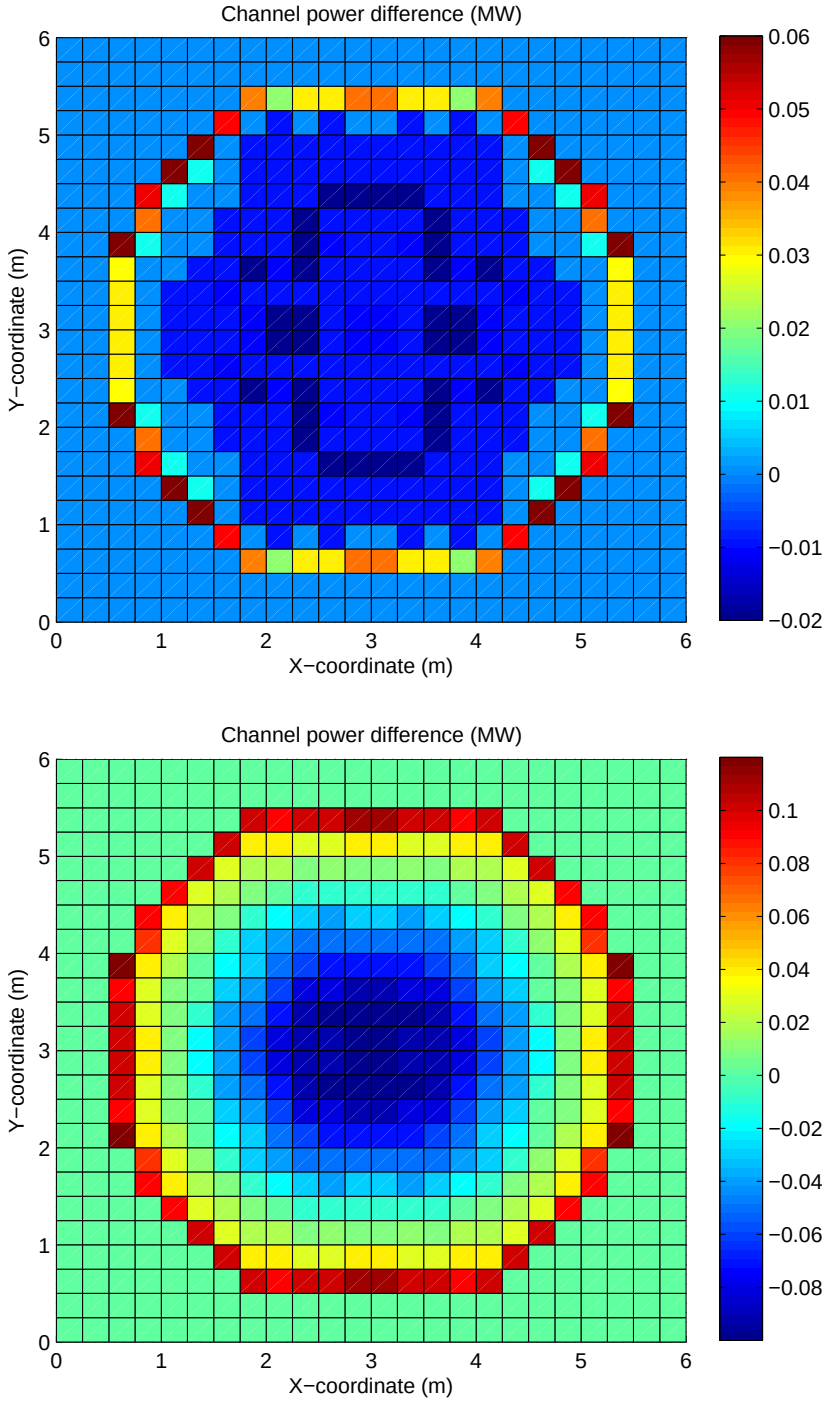


Figure 1.11 Difference in channel power (CPO results - AFM results) for Simulation condition 1 (top) and Simulation condition 2 (bottom)

CHAPTER 2

STEADY-STATE ANALYSIS

After generating and validating the cross-section database, the next step is to implement a reactor-core model, a thermalhydraulics model, a heat-transfer model, and a neutronics/thermalhydaulics coupling methodology.

2.1 Reactor-core model

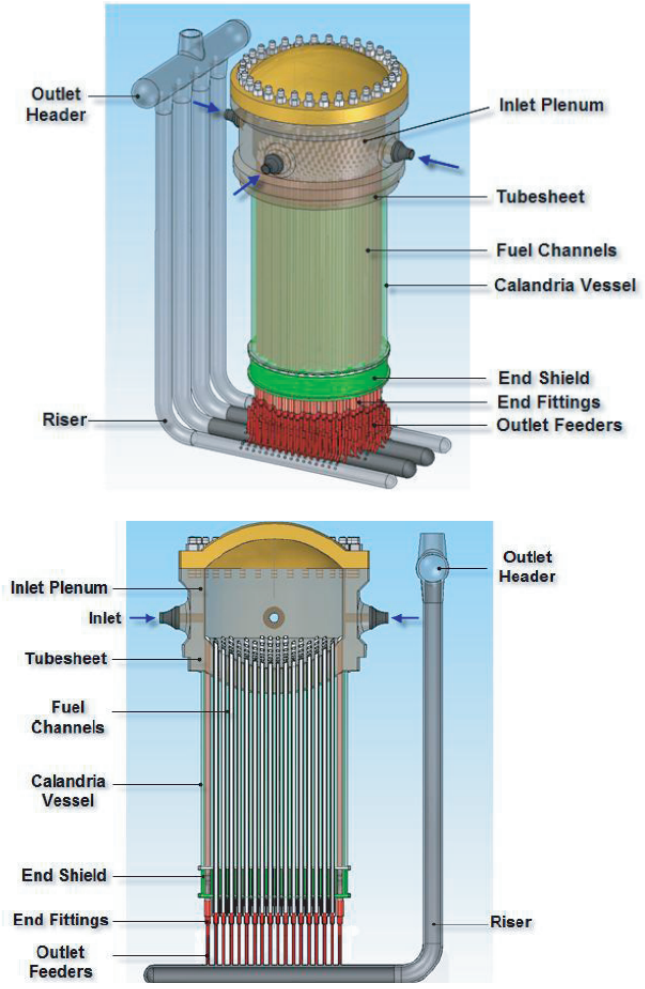


Figure 2.1 Reactor core: outside view (top) and inside view (bottom)

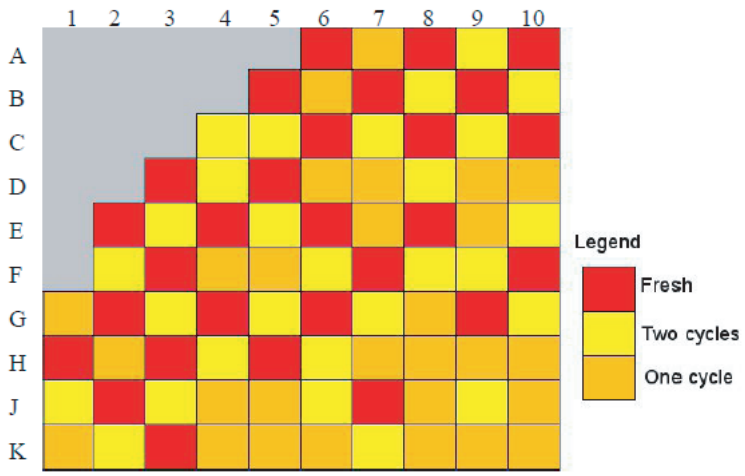


Figure 2.2 Fuel loading map

The reactor is made of 336 channels of 5 m in length. It has a vertical orientation, and the coolant flows downward. As Figure 2.1 shows, the coolant enters the inlet plenum through inlet pipes. It spreads across all channels in such a way as to maintain an even channel input mass-flow rate and temperature. It then flows through the channels all the way to the outlet header (MacDonald *et al.*, 2011).

In contrast to the CANDU 6 reactor, this reactor design does not support online refueling, and one possible reason for this choice is the need for a new refueling machine design to deal with supercritical water. As a result, the designers of this reactor plan on using a three-batch scheme in which one third of the core contains fresh fuel, one third contains fuel having spent a loading cycle in the core, and the remaining third has fuel having spent two loading cycles. The cycle length depends on the fuel composition, and the designers chose the fuel arrangement of Figure 2.2 so as to minimize the power peaking factor (MacDonald *et al.*, 2011).

Although the designers intent to use a three-batch scheme, the present study is done with the assumption that the core is filled with fresh fuel; furthermore, neither reactivity control mechanisms nor burnable absorbers are taken into account.

2.2 Thermalhydraulics and heat-transfer models

In order to perform a thermalhydaulics and heat-transfer analysis, the THERMO: module (Adouki, 2011) has been included in the DONJON code. Let z be an axial location measured from the channel inlet; the module determines the fuel temperature $t_f(z)$, the cladding temperature $t_g(z)$, the coolant pressure $p(z)$, the coolant density $\rho_c(z)$, and the coolant tem-

perature $t_c(z)$ at the axial location z from $p(0)$, $\dot{m}$, $q^{''}(z)$, $\rho_c(0)$, and $t_c(0)$. Solving this problem requires models for thermalhydraulics and heat-transfer. The following models are known to give satisfactory results:

- 1-D model for thermalhydaulics (Tapucu, 2009).
- Doubly-lumped parameter model for heat-transfer (Lewis, 1977).

During constant-power conditions, the core-power distributions changes; therefore, thermalhydaulics parameters change with time. However, their rates of change are so small that they can be ignored, as it is commonly done. As a result, steady-state models for thermalhydaulics and heat transfer are used in this chapter.

2.2.1 Thermalhydaulics model

The 1-D thermalhydaulics model is based on the following conservation laws:

- Mass:

$$\dot{m}(z) = \text{constant} \tag{2.1}$$

- Momentum:

$$\frac{dP(z)}{dz} = -\frac{fG^2}{2\rho_c(z)D_h} - G^2\frac{d\left(\frac{1}{\rho_c(z)}\right)}{dz} + \rho_c(z)g \tag{2.2}$$

- Energy:

$$\frac{dH(z)}{dz} = \frac{2\pi q^{''}(z)R_{rod}N_{rod}}{\dot{m}} \tag{2.3}$$

Not having an adequate correlation for the friction factor f, the following assumption is made:

$$-\frac{fG^2}{2\rho_c(z)D_h} + \rho_c(z)g = 0 \tag{2.4}$$

so that the momentum conservation becomes:

$$\frac{dP(z)}{dz} = -G^2\frac{d\left(\frac{1}{\rho_c(z)}\right)}{dz} \tag{2.5}$$

Applying the conservation laws between z and $z + \Delta z$, for Δz small, gives for the monentum equation

$$P(z + \Delta z) = P(z) - G^2\left(\frac{1}{\rho(z + \Delta z)} - \frac{1}{\rho(z)}\right) \tag{2.6}$$

while the energy equation becomes

$$H(z+\Delta z) - H(z) = \frac{2\pi q^{''}(z)\Delta z R_{rod} N_{rod}}{\dot{m}} \tag{2.7}$$

The relation

$$H(z+\Delta z) - H(z) = c_p(z)\left(t_c(z+\Delta z) - t_c(z)\right) \tag{2.8}$$

gives

$$t_c(z+\Delta z) = \frac{2\pi q^{''}(z)\Delta z R_{rod} N_{rod}}{\dot{m} c_p(z)} + t_c(z) \tag{2.9}$$

The heat-transfer coefficient is

$$h_c(z) = \frac{k_c(z) Nu(z)}{D_{he}} \tag{2.10}$$

From (MacDonald *et al.*, 2011), we obtain that:

$$Nu(z) = 0.023 Re^{0.8}(z) Pr^{0.4}(z) \tag{2.11}$$

$$D_{he} = \frac{4A_{flow}}{P_{he}} \tag{2.12}$$

$$P_{he} = \pi\left(D_c + n_{R1}D_{R1} + n_{R2}D_{R2} + n_{R3}D_{R3}\right) \tag{2.13}$$

$$A_{flow} = \frac{\pi}{4}\left(D_{liner}^2 - D_c^2 - n_{R1}D_{R1}^2 - n_{R2}D_{R2}^2 - n_{R3}D_{R3}^2\right) \tag{2.14}$$

$$D_h = \frac{4A_{flow}}{P_{wet}} \tag{2.15}$$

$$P_{wet} = \pi\left(D_{liner} + D_c + n_{R1}D_{R1} + n_{R2}D_{R2} + n_{R3}D_{R3}\right) \tag{2.16}$$

$$Pr(z) = \frac{c_p(z)\mu(z)}{k_c(z)} \tag{2.17}$$

2.2.2 Heat-transfer model

The heat-transfer model is based on the doubly-lumped parameter model, and it has the following attributes:

- It neglects the axial heat transfer along the fuel and the cladding.
- Instead of using $t_f(z,r)$ and $t_g(z,r)$, it uses their channel-averaged values in the radial direction, between z and $z+\Delta z$, denoted by $t_f(z)$ and $t_g(z)$, respectively.

By using the energy balance in the fuel and in the cladding, between z and $z + \Delta z$, we obtain for each fuel rod:

$$
\begin{aligned}
&q'''(z)V_f - Q_1(z) = 0 \\
&Q_1(z) - Q_2(z) = 0 \\
&Q_2(z) = h_c(z)A_g[t_g(z) - t_c(z)] \\
&Q_1(z) = A_f h_{gap}[t_f(z) - t_g(z)]
\end{aligned}
$$

Therefore,

$$t_g(z) = \frac{q'''(z)V_f}{h_c(z)A_g} + t_c(z) \tag{2.18}$$

$$t_f(z) = \frac{q'''(z)V_f}{h_g(z)A_f} + t_g(z) \tag{2.19}$$

2.3 Reactor-power calculation procedure

The multigroup steady state diffusion equation is given by (Hébert, 2008)

$$-\nabla \cdot D_g(\mathbf{r})\nabla\phi_g(\mathbf{r}) + \Sigma_g(\mathbf{r}) = Q_g(\mathbf{r}) \tag{2.20}$$

The source term is

$$Q_g(\mathbf{r}) = \sum_{h=1}^{G} \Sigma_{g\leftarrow h}(\mathbf{r})\phi_g(\mathbf{r}) + \frac{\chi_g(\mathbf{r})}{K_{eff}} \sum_{h=1}^{G} \nu\Sigma_{fh}(\mathbf{r})\phi_h(\mathbf{r}) \tag{2.21}$$

The reactor core model is implemented with the 3-D diffusion code DONJON version 3.02B (Varin *et al.*, 2005), and calculations are performed with two energy groups. Each channel is partitioned into 10 cells of length, width, and height 25 cm, 25 cm, and 50 cm, respectively. The flux in each cell is determined by the *Mesh-Centered-Finite-Difference Approximation*. At the onset of a power calculation (Figure 2.3), the GEOD: creates the core geometry which consists of 10 planes of 576 cells each, 336 cells of which are fuel ones. The USPLIT: module performs mesh splitting on the geometry and determines new mixtures indices so that every mixture index corresponds to only one sub-region. After the mesh splitting is completed, the TRIVAT: module performs a TRIVAC-type tracking on the geometry, and the geometry is then used by the INIRES: module to create a fuel map. The fuel map contains information on each fuel cell, such as fuel burnup, fuel power, fuel temperature, coolant temperature, and

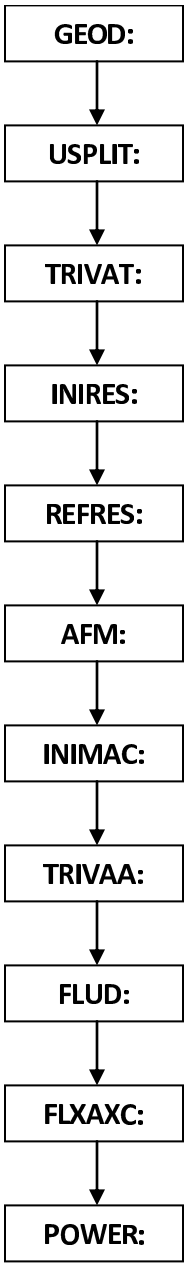


Figure 2.3 Power calculation procedure

coolant density. The REFRES: module establishes a correspondance between the calculation geometry, the material indices, and the fuel map; this singles out indices that refer to mixtures in fuel cells from indices that do not. By using the information about each cell, the AFM: module creates two macroscopic cross sections data structures: one for fuel cells and the other one for reflector cells. These data structures are combined into a single one by the UNIMAC: module, and this allows the TRIVAA: module to create systems matrices necessary for flux calculations. The FLUD: module determines the flux distribution in the core, which is then averaged over each cell by the FLXAXC: module. Finally, the POWER: module uses the average flux and the total core power, to determine the power in each cell.

2.4 Thermalhydraulics calculation procedure

The goal of the new THERMO: module is to determine, for each channel, the fuel temperature $t_f(z)$, the cladding temperature $t_g(z)$, the coolant pressure $p(z)$, the coolant density $\rho_c(z)$, and the coolant temperature $t_c(z)$ at the axial location z from $p(0)$, $\dot{m}$, $q''(z)$, $\rho_c(0)$, and $t_c(0)$. The module uses the finite-volume method, the conservation laws, and the NIST Standard Reference Database 23 (NIST, 2011) to determine the unknown parameters. Calculations are based on the value of $h_{gap} = 10$ kW/m^2/^{o}C (Rozon, 1998) and the channel design parameters depicted in Table 2.1 (MacDonald *et al.*, 2011). The algorithm of the module is given in Figure 2.4. It is based on the assumption that an equation of state, giving all the thermodynamic properties of water, is available. Thus, after selecting a channel, the module determines $h_c(z)$, $t_g(z)$, and $t_f(z)$ from $t_c(z)$ and $p(z)$ by using equations 2.10 through 2.19. $t_c(z+\Delta z)$ is calculated from equation 2.9 by using $p(z)$, $t_c(z)$, and the bundle powers for the channel being analyzed, and equations 2.10 through 2.20 allow the calculation of $h_c(z+\Delta z)$, $t_g(z+\Delta z)$, and $t_f(z+\Delta z)$ from $t_c(z+\Delta z)$ and $p(z)$. Finally, Equation 2.6 gives $p(z+\Delta z)$ from $p(z)$ and $t_c(z+\Delta z)$.

Table 2.1 Channel design parameters

Parameter	Value
Inlet pressure (MPa)	26
Inlet temperature (^{o}C)	350
Channel massflow rate (Kg/s)	3.89

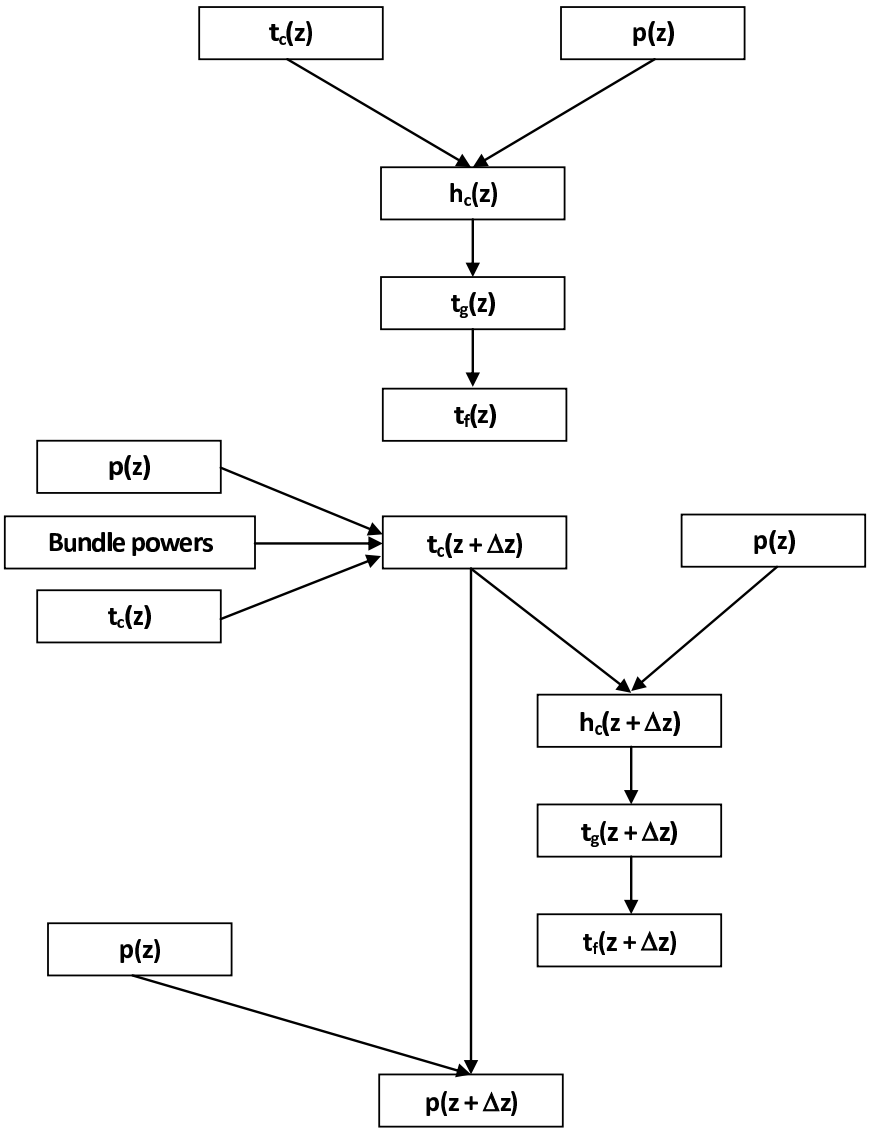


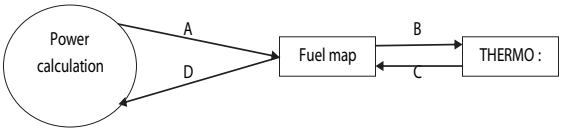
Figure 2.4 Thermalhydraulics calculation procedure

2.5 Description of the neutronics/thermalhydraulics coupling procedure

The THERMO: module exchanges data with the rest of the DONJON code, through the fuel map file that contains the data for each cell (Figure 2.5 top). In Figure 2.5 (bottom), the method starts with a core-power calculation performed from the default thermalhydaulics parameters given in Table 2.2. The resulting bundle powers are saved into the fuel map. Bundle powers are then read from the fuel map, and the THERMO: module determines the coolant temperature, the coolant density, and the fuel temperature of each cell, and this data is saved into the fuel map. The fuel temperature, coolant temperature, and coolant density of each bundle are then read, and bundle powers are computed through a full-core calculation, based on the temperature and density data of each cell; the AFM: module uses this data to determine the cross sections of each cell. The resulting bundle powers are again saved. This process is repeated until the convergence of the effective multiplication factor is reached.
Note: In Figure 2.5, the initialization $keff_{(i-1)} = 0$ is done so as to ensure that at least the second iteration is performed.

Table 2.2 Default local and global parameters for the THERMO: module

Material	Density (Kg/m^3)	Temperature (K)
Fuel	N.A.	1273.15
Coolant (light water)	350	923.15
Moderator (heavy water)	1085.09	342.16



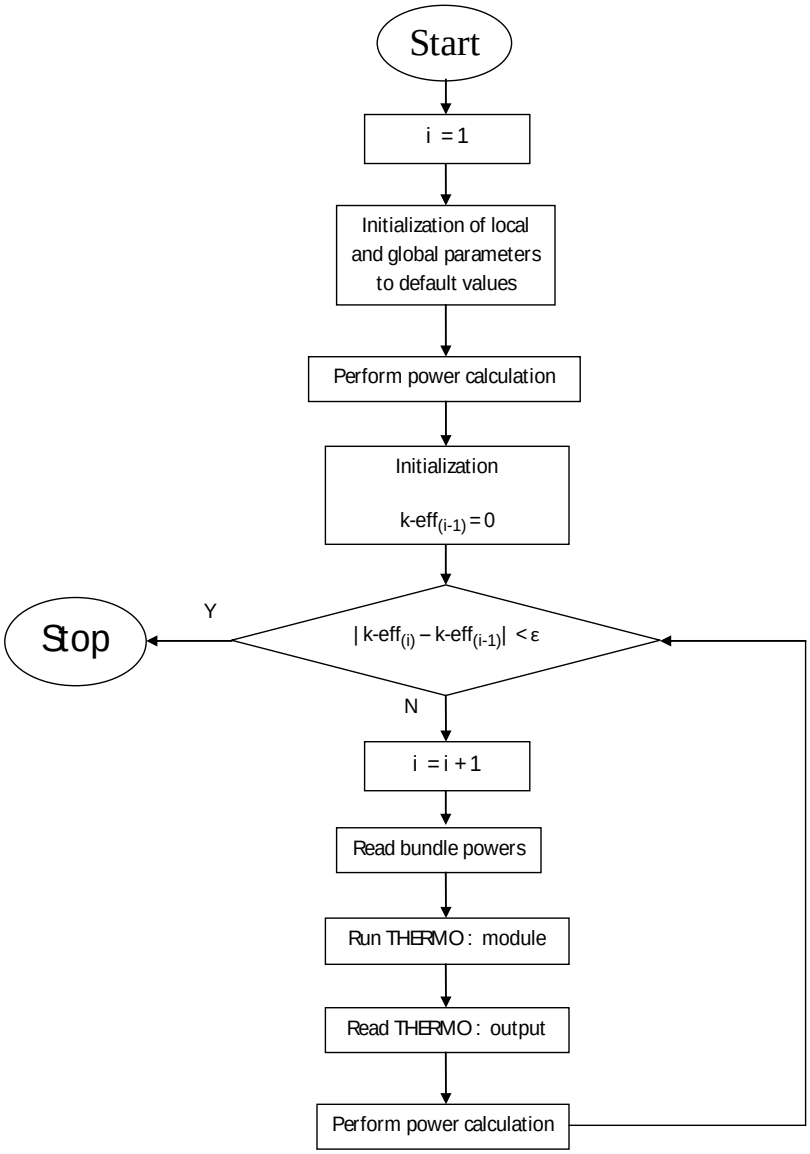


Figure 2.5 Flow chart of coupling calculations

2.6 Validation tests for the THERMO: module

In order to validate the THERMO: module, three tests are performed in which the results of the THERMO: module are compared to those of AECL.

2.6.1 Test 1

In this test, the coolant temperature and density, for the average-power channel, are used as validation parameters. First, the core power is calculated with the fuel arrangement of Figure 2.2 and homogeneous thermalhydaulics parameters. Then, the resulting coolant temperature and density are determined without a neutronics/thermalhydaulics coupling; therefore, in this channel, the power is symetrical with respect to the normal plane to the channel axis, at 2.5 m from the channel inlet. Also, the mass flow rate used is selected so as to have a coolant output temperature of 625 ^{o}C while a constant channel pressure of 25.1 MPa is assumed. The coolant temperature and density predicted by THERMO: agree with those calculated by AECL, within 3%. Even though both data sets agree well (Figure 2.6), the graphs obtained with the THERMO: module show some discontinuities in the slope, whereas those obtained by AECL are smooth. The discontinuities occur only between two adjacent bundles. They result from the fact that the average power of each bundle was used in thermalhydraulics calculations. From Equation 2.9, the slope of the coolant-temperature curve is given by $\frac{2\pi q^{''}(z) R_{rod} N_{rod}}{\dot{m} c_p(z)}$, and $q^{''}(z)$ may have discontinuities at the interface of two bundles and accordingly affect the slope at these locations.

2.6.2 Test 2

This test uses the bundle powers of the maximum-power channel as the validation parameter. In the case of THERMO:, the core power is determined through a neutronics/thermalhydraulics coupling procedure under the assumption that the core is filled with fresh fuel only. Thermalhydaulics calculations are done with a channel mass-flow rate of 3.89 Kg/s. In the case of AECL, the same neutronics/thermalhydaulics coupling method is performed with a channel mass-flow rate of 3.89 Kg/s and the fuel loading pattern of Figure 2.2; Figure 2.7 gives the results. The AECL graph shows results both at the beginning of cycle (blue curve) and at the end of cycle (red curve). The result comparison at the beginning of cycle indicates a power peak at the third bundle (from the channel input) in the case of THERMO: and at the fourth bundle in the case of AECL. Also, the power peak predicted by THERMO: is higher than that predicted by EACL since only fresh fuel is used in the THERMO: core model, while a combination of fresh and spent fuel is used in the AECL core model (Figure 2.2). Moreover, the use of spent fuel shifts the power peak to the right, as it

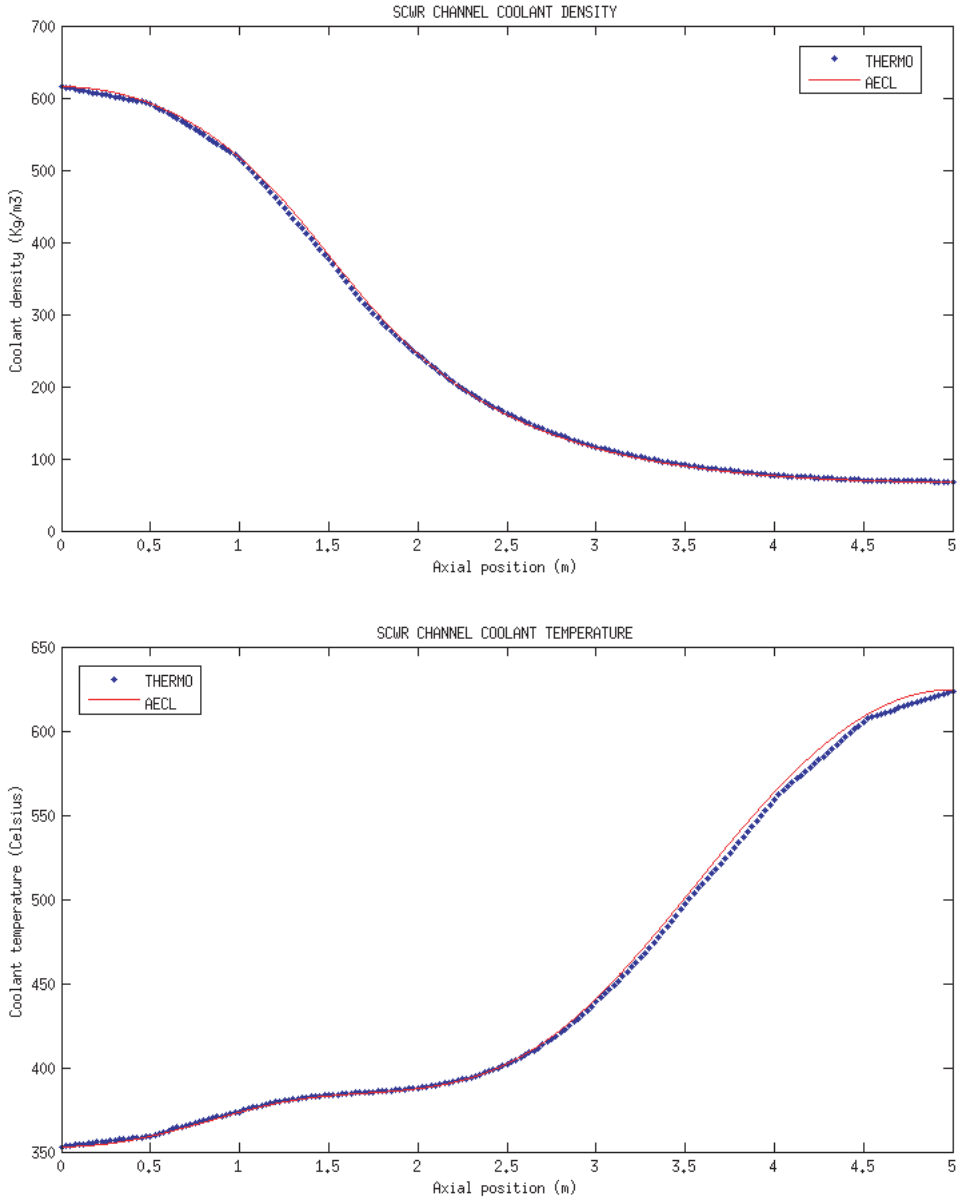


Figure 2.6 Comparison of density (top) and temperature (bottom) obtained from THERMO: and AECL

is the case for the AECL results. Therefore, the power obtained with THERMO: agrees with that obtained by EACL.

2.6.3 Test 3

This final test uses the coolant and the cladding temperatures, of the average-power channel, as validation parameters. The assumptions are similar to those of Test 2, with the exception that a constant channel pressure of 25 MPa is taken into account. In Figure 2.8, the coolant temperature predicted by THERMO: is similar to that predicted by AECL, with the exception that the peak in the temperature given by THERMO: is lightly shifted to the left of the one predicited by AECL. For the cladding temperature, both data sets show peaks next to the channel inlet; the peak predicted by THERMO: is higher than that predicted by AECL. Another observation from Figure 2.8 is that the cladding temperatures determined by THERMO:, for the last 5 bundles in the channel, are lower than their corresponding values given by AECL; this is because THERMO: predicts a bundle-power profile that is shifted to the left of the one predicted by AECL.

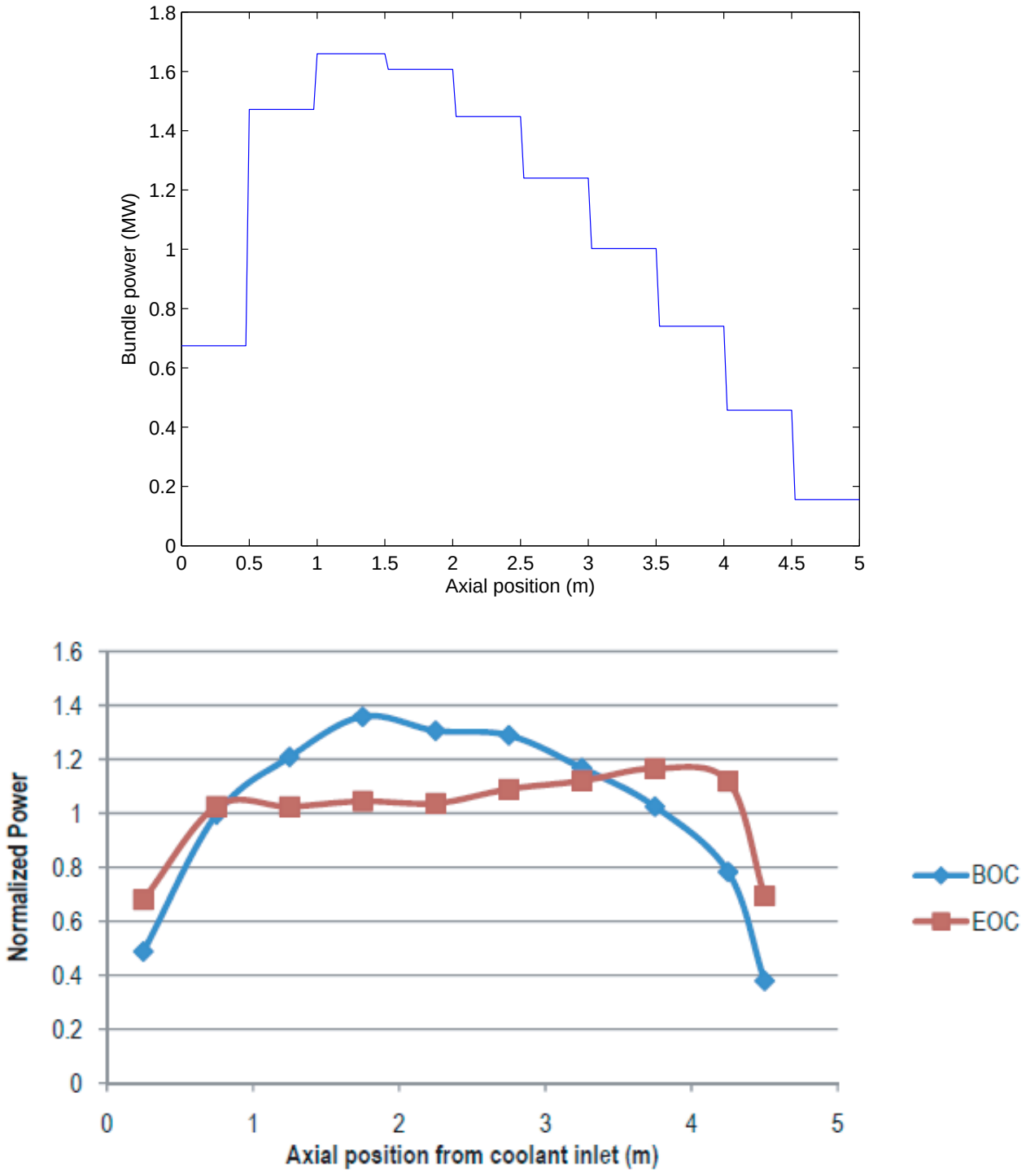


Figure 2.7 Comparison of bundle power obtained from THERMO (top) and AECL (bottom)

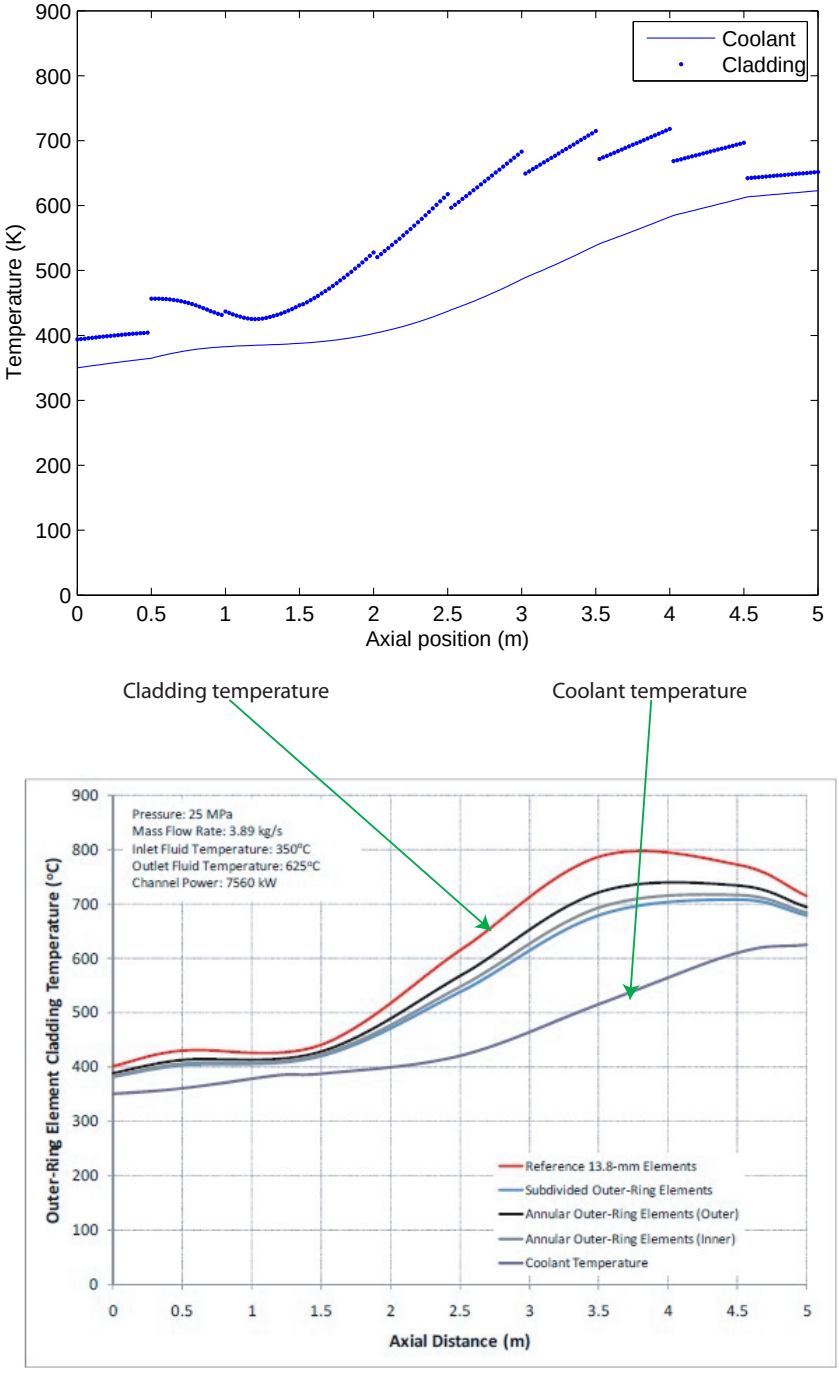


Figure 2.8 Comparison of coolant and cladding temperatures obtained from THERMO: (top) and AECL (bottom)

CHAPTER 3

RESULTS FOR STEADY-STATE ANALYSIS

The neutronics/thermalhydraulics method, introduced in the previous chapter, is used to determine the core power and the thermalhydraulics parameters of its channels. These results are presented in this chapter.

3.1 Effective multiplication factor

Table 3.1 Effective multiplication factor

K_{eff}	Iteration number
1.149594E+00	1
1.164142E+00	2
1.155806E+00	3
1.159475E+00	4
1.157450E+00	5
1.158354E+00	6
1.157941E+00	7
1.158120E+00	8
1.158044E+00	9
1.158075E+00	10
1.158063E+00	11
1.158068E+00	12

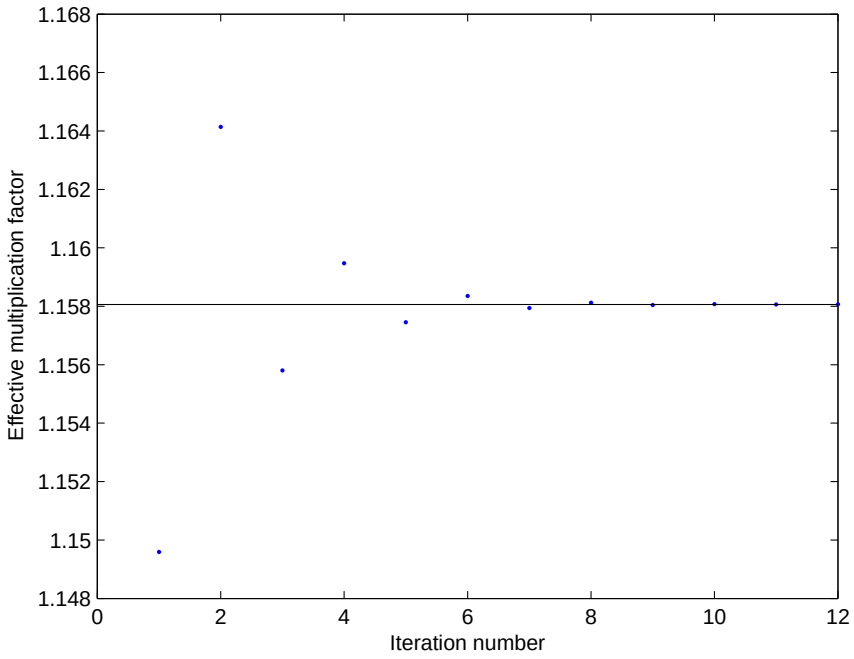


Figure 3.1 Values of the K_{eff} during iterations

In Table 3.1 and Figure 3.1, the value of the effective multiplication factor oscillates around the convergence value. If one iteration under-estimates the K_{eff}, the next one will over-estimate it, and vice-versa. This process is repeated until convergence, as the difference between successive values of the K_{eff} decreases. The value $\epsilon = 10^{-5}$ is used in the convergence condition for the K_{eff} in Figure 2.5.

3.2 Channel-power distribution

Figure 3.2 shows that the channel power is not evenly distributed; most channels have a power larger than the average channel power (7.556 MW). The high power density at the center of the core results from the use of fresh fuel without any reactivity control mechanisms. The results are as follows:

- Maximum channel power: 10.55 MW
- Minimum channel power: 4.05 MW
- Power peaking factor: 1.4

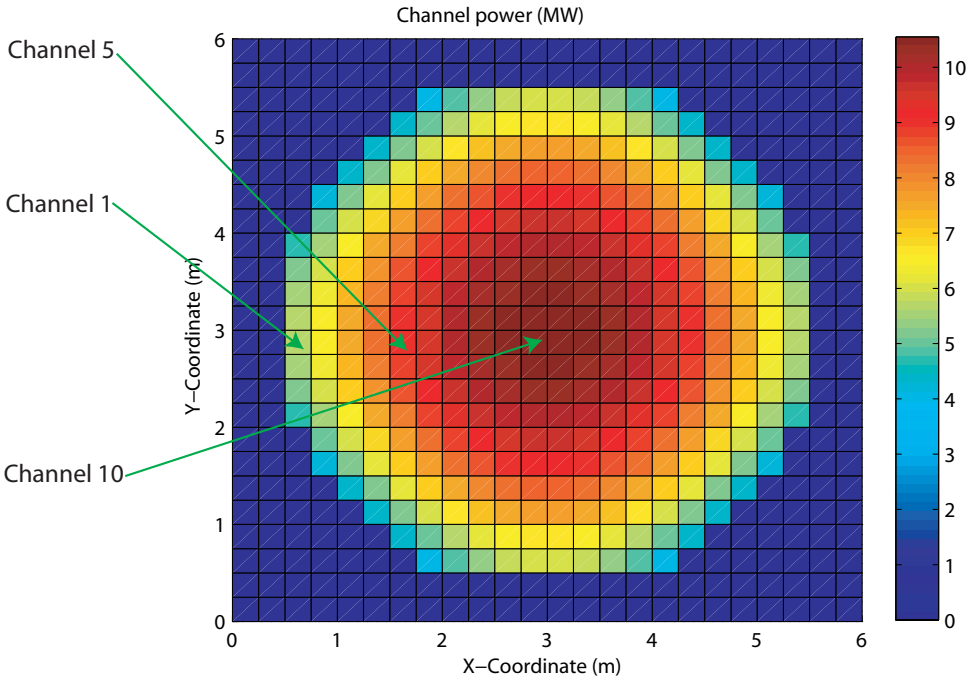


Figure 3.2 Channel-power distribution at convergence

3.3 Results for channel 1

3.3.1 Bundle power

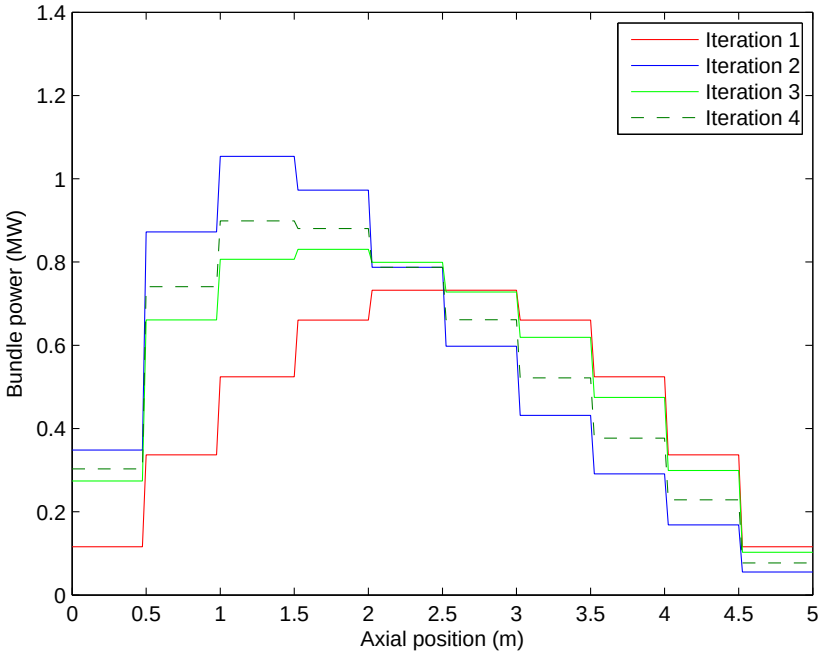


Figure 3.3 Bundle power at the first 4 iterations

In Figure 3.3, each iteration either over-estimates a bundle power, or under-estimates it. If a bundle power is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive bundle powers diminishes, from one iteration to the next one. Also, the location of the bundle-power peak oscillates during iterations. If it is under-estimated at one iteration, it will be over-estimated at the next iteration. This process is repeated until convergence is reached (Figure 3.4), at which point the bundle-power peak is located at the third bundle from the channel inlet.

Even though a convergence test was only applied to the K_{eff} in Figure 2.5, the results of Figure 3.4 show that the convergence criterion used, in Figure 2.5, is sufficient to garantee the convergence of the power and, consequently, the convergence of thermalhydraulics parameters.

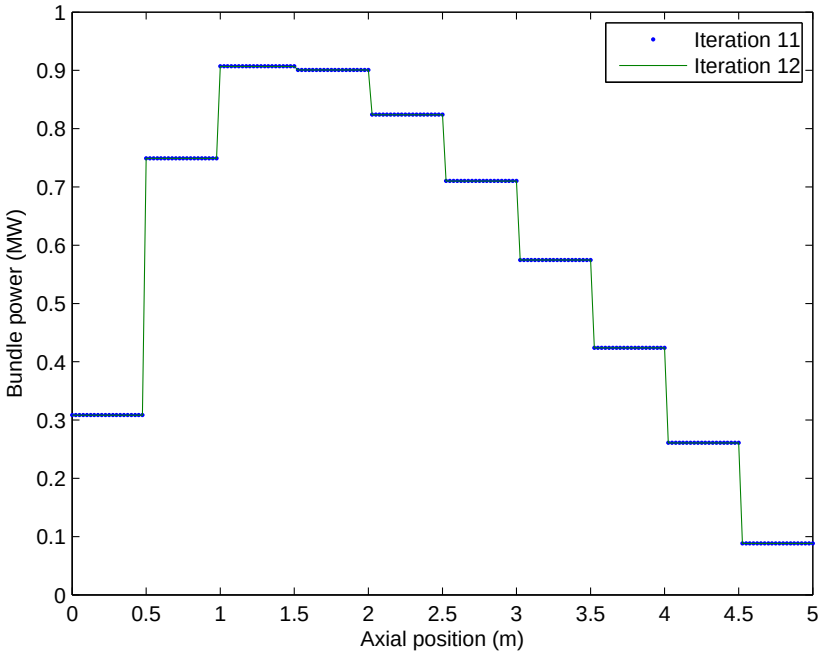


Figure 3.4 Bundle power at convergence

3.3.2 Specific-heat capacity

Studies have shown, in the case of supercritical water, that the specific-heat capacity has its maximum value at the pseudo-critical point (Pioro and Duffey, 2007). Therefore, Figures and 3.5 and 3.6 give the locations of the pseudo-critical point from one iteration to another. Each iteration either over-estimates a specific-heat capacity, or under-estimates it. If a value of the specific-heat capacity is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the specific-heat diminishes, from one iteration to the next one. Moreover, each iteration either over-estimates the position of the pseudo-critical point, or under-estimates it. If an iteration under-estimates this position, the next iteration will over-estimate it, and vice-versa. This process is repeated as the difference between successive positions of the pseudo-critical point diminishes, from one iteration to the next one.

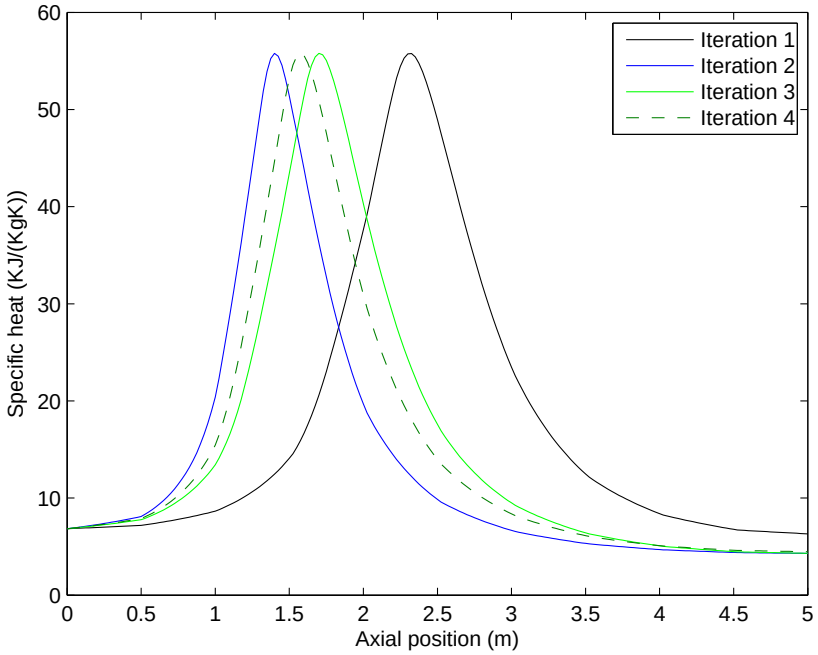


Figure 3.5 Specific-heat capacity at the first 4 iterations

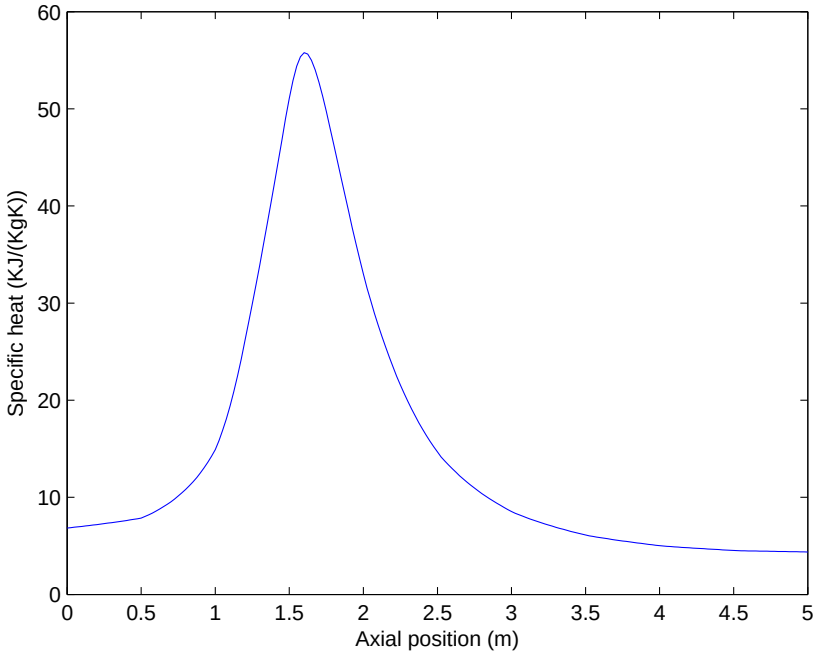


Figure 3.6 Specific-heat capacity at convergence

3.3.3 Heat-transfer coefficient

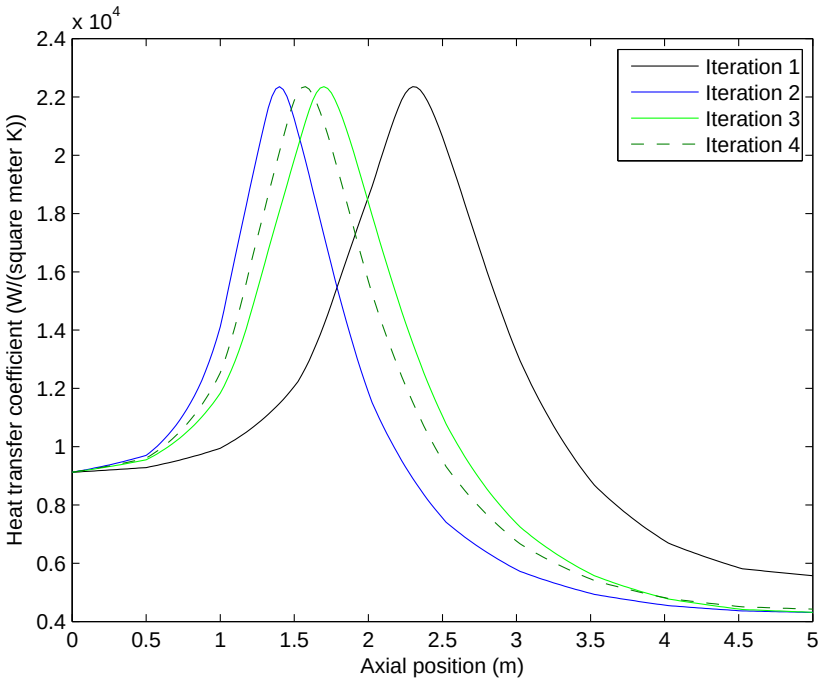


Figure 3.7 Heat-transfer coefficient at the first 4 iterations

An analysis of the heat-transfer coefficient in a channel is useful in understanding its temperature profiles. In this study, the maximum of the heat-transfer coefficient coincides with that of the specific-heat capacity (Figures 3.5 and 3.7). Also, if a value of the heat-transfer coefficient is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the heat-transfer coefficient diminishes, from one iteration to the next one. At convergence, the position of the peak of the heat-tranfer coefficient coincides with that of the specific-heat capacity (Figures 3.6 and 3.8).

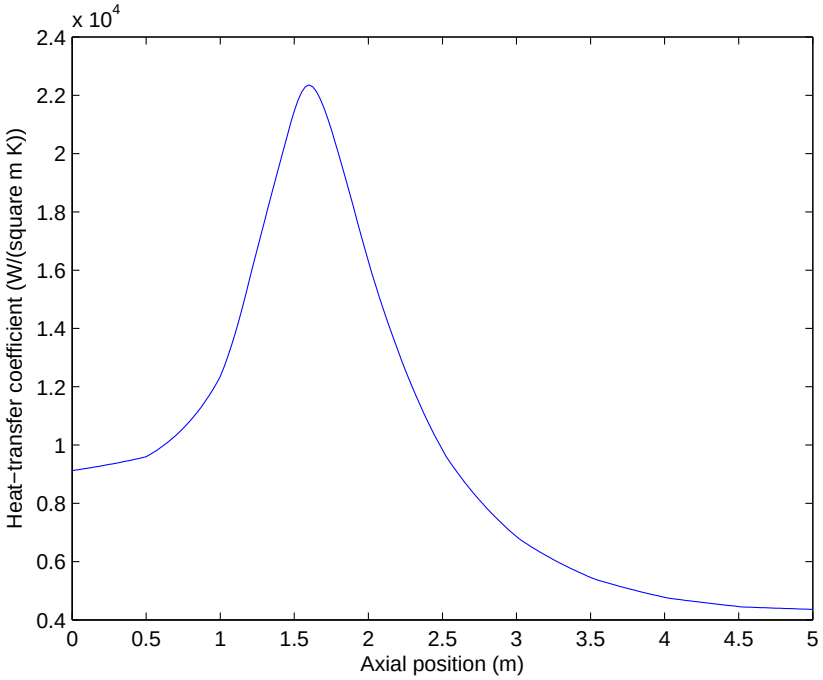


Figure 3.8 Heat-transfer coefficient at convergence

3.3.4 Coolant temperature

The coolant temperature increases rapidly at the approach of the peak of the heat-transfer coefficient (Figure 3.9); when the heat-transfer coefficient is maximum, the rate of heat transfer to the coolant is also maximum. Also, if a value of the coolant temperature is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant temperature diminishes, from one iteration to the next one, until convergence is reached (Figure 3.10).

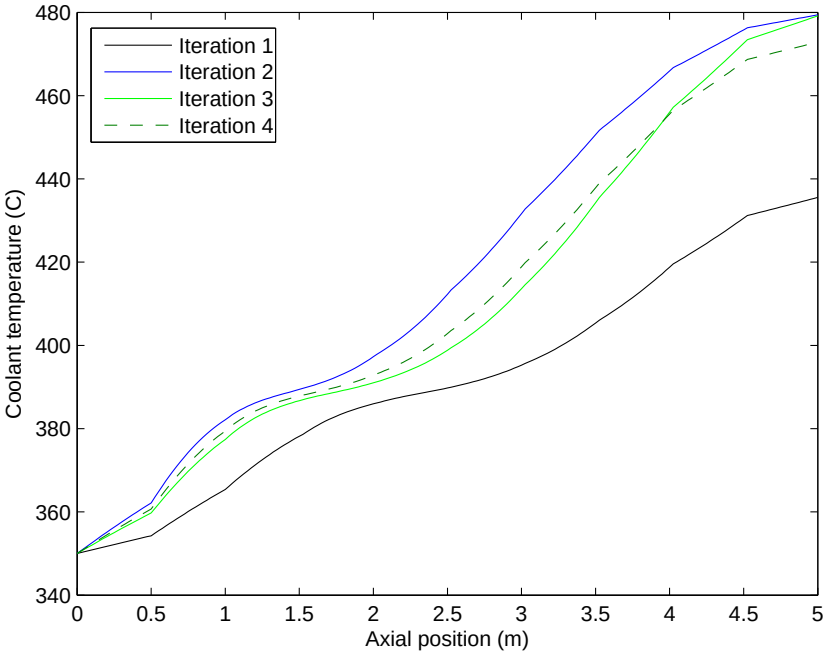


Figure 3.9 Coolant temperature at the first 4 iterations

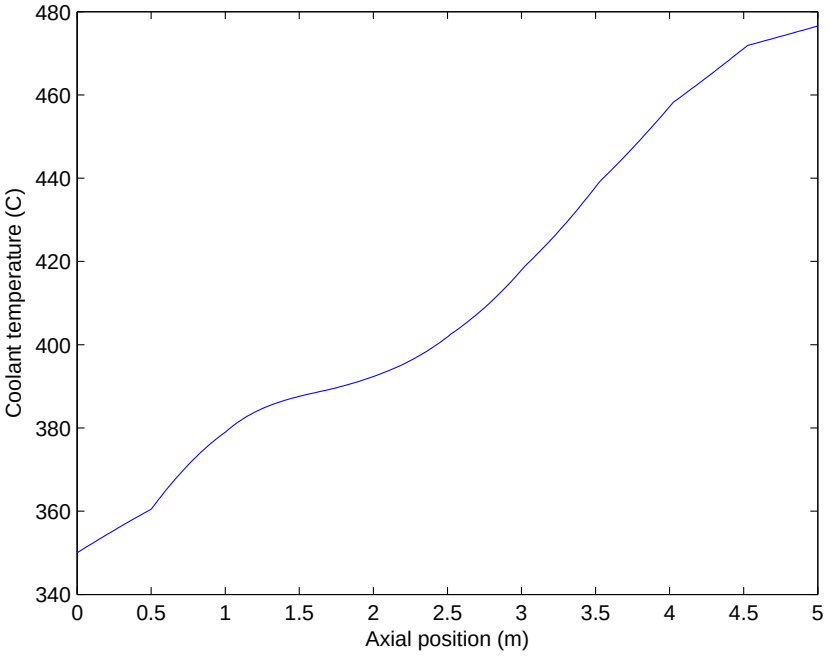


Figure 3.10 Coolant temperature at convergence

3.3.5 Coolant density

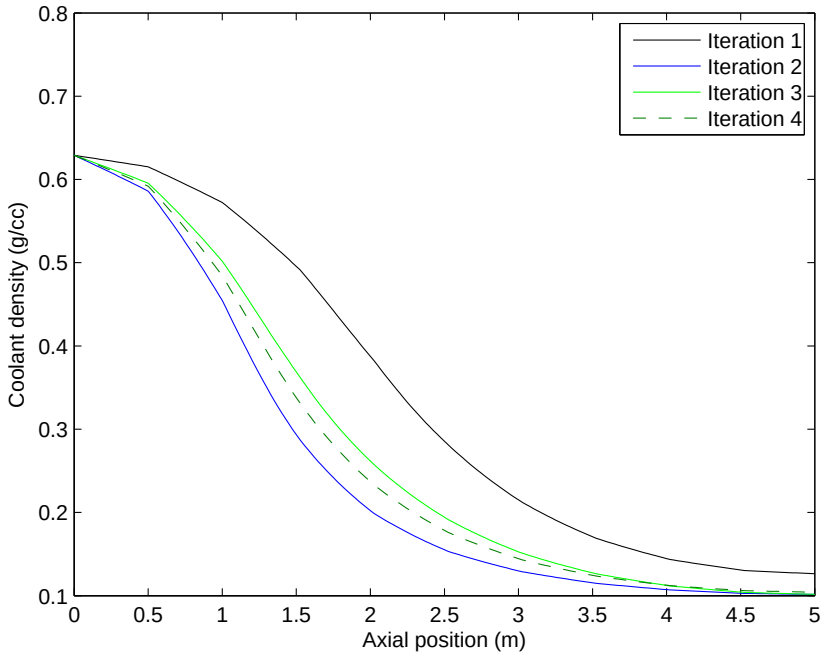


Figure 3.11 Coolant density at the first 4 iterations

It is known that, for supercritical water, the coolant density varies rapidely around the pseudo-critical point (Pioro and Duffey, 2007). As a result, since the location of the pseudo-critical point changes from one iteration to another, the shape of the density curve is affected by each iteration until convergence is reached. Moreover, if a value of the coolant density is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant density diminishes, from one iteration to the next one (Figures 3.11 through 3.12).

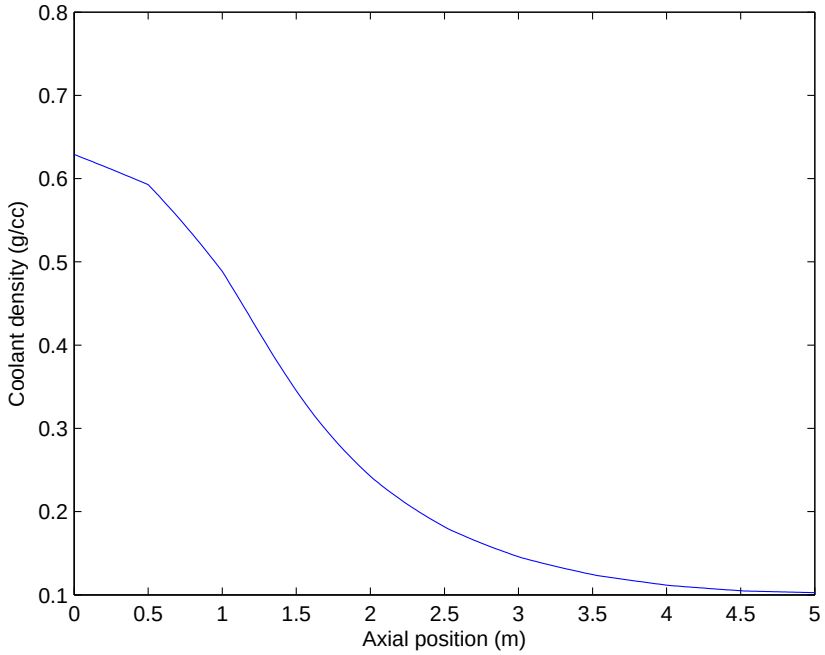


Figure 3.12 Coolant density at convergence

3.3.6 Pressure along the channel

In general, the pressure drop is determined by the energy transfer resulting from friction, acceleration, or gravity. The friction and gravity contributions are neglected in Equation 2.4. Therefore, the pressure drop obtained in this chapter is only determined by the coolant-density changes in the channel. Consequently, the higher the coolant-density gradient, the higher the coolant-pressure gradient (Figures 3.11 through 3.14). Also, if one iteration under-estimates the pressure, the next one over-estimates it, and vice-versa. This process is repeated until convergence is reached.

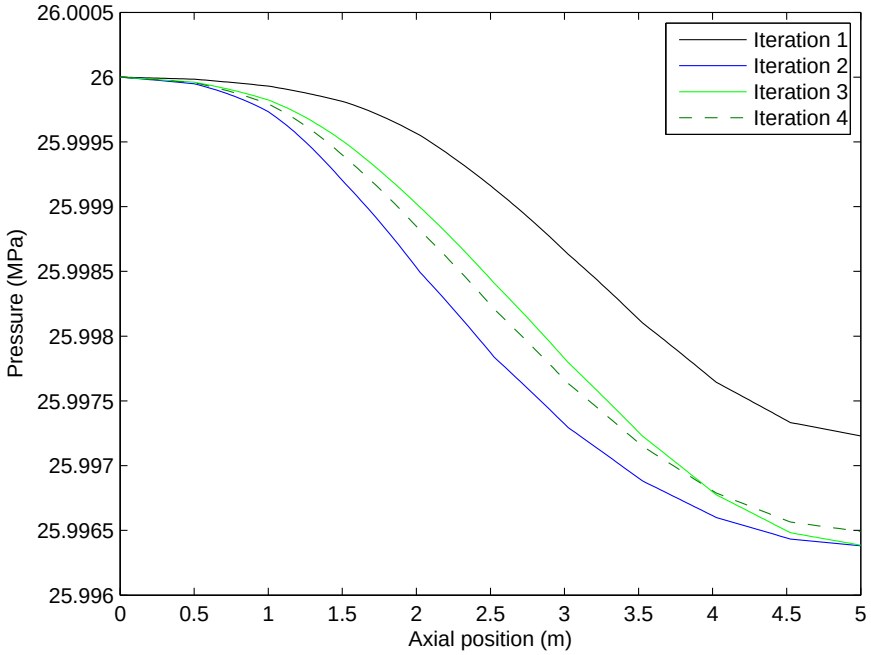


Figure 3.13 Pressure at the first 4 iterations

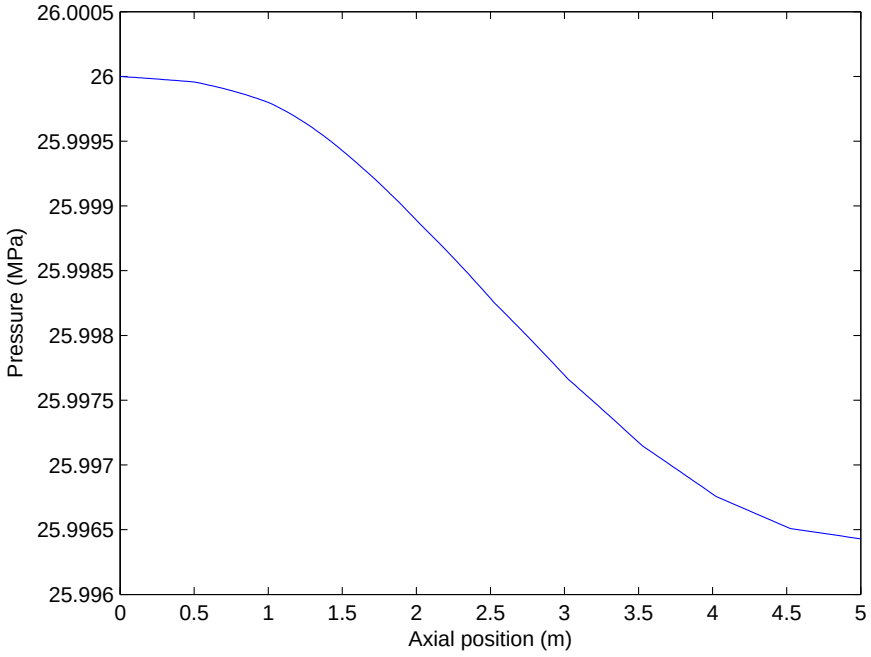


Figure 3.14 Pressure at convergence

3.3.7 Fuel and cladding temperatures

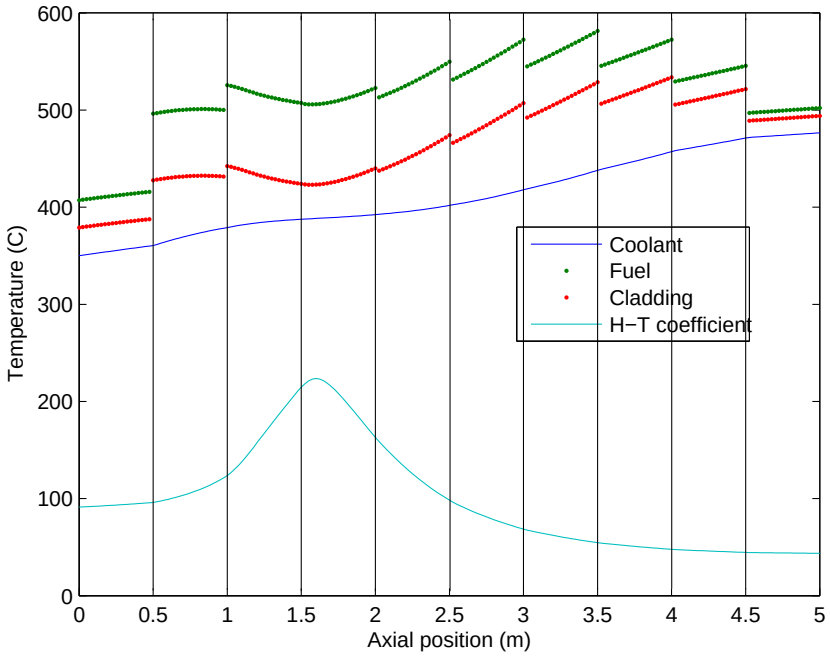


Figure 3.15 Data at convergence; heat-transfer (H-T) coefficient in 100 $W \cdot (m^2 \cdot K)^{-1}$

In Figure 3.15, the fuel and cladding temperatures, for bundles next to the channel inlet, increase due to the low heat-transfer coefficient. Around the pseudo-critical point, they decrease with the rapid increase in the heat-transfer coefficient. Towards the end of the channel, they increase as a result of the low heat-transfer coefficient. The discontinuity in the fuel and cladding temperatures, for adjacent bundles, results from the discontinuity of the power from one bundle to the next one. Moreover, the center-line temperatures for the fuel and the cladding may be lower than their fusion temperatures (3300 Celsius for the fuel and 850 Celsius for the cladding), since their radially-averaged values are below these limits.

3.4 Results for channel 5

3.4.1 Bundle power

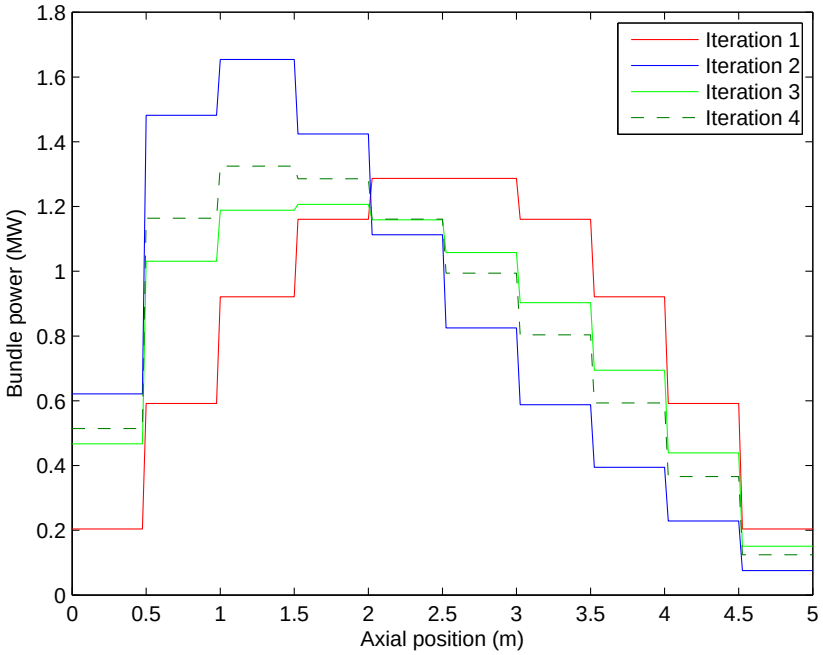


Figure 3.16 Bundle power at the first 4 iterations

In Figure 3.16, each iteration either over-estimates a bundle power, or under-estimates it. If a bundle power is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive bunder powers diminishes, as convergence is approached (Figure 3.16). Also, the location of the bundle-power peak oscillates during itetations. If it is under-estimated at one iteration, it will be over-estimated at the next iteration. This process is repeated until convergence is reached (Figure 3.17), at which point the bundle-power peak is located at the third bundle from the channel inlet. Furthermore, the value of the peak bundle power for Channel 5 is larger than that of Channel 1 since Channel 5 has a higher power.

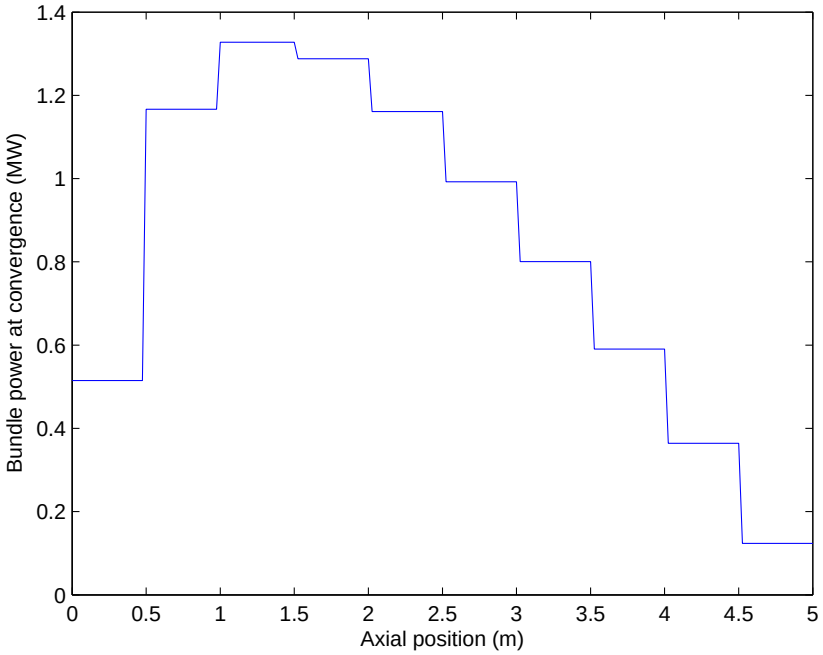


Figure 3.17 Bundle power at convergence

3.4.2 Specific-heat capacity

In Figure 3.18, each iteration either over-estimates the specific heat, or under-estimates it. If a value of the specific heat capacity is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the specific heat capacity diminishes, from one iteration to the next one. Moreover, each iteration either over-estimates the position of the pseudo-critical point, or under-estimates it. If an iteration under-estimates this position, the next iteration will over-estimate it, and vice-versa. This process is repeated as the difference between successive positions of the pseudo-critical point diminishes, from one iteration to the next (Figure 3.18). At convergence, the peak of the specific-heat capacity of Channel 5 is shifted to the left of the one for Channel 1, due to the higher power of Channel 5 (Figures 3.6 and 3.19).

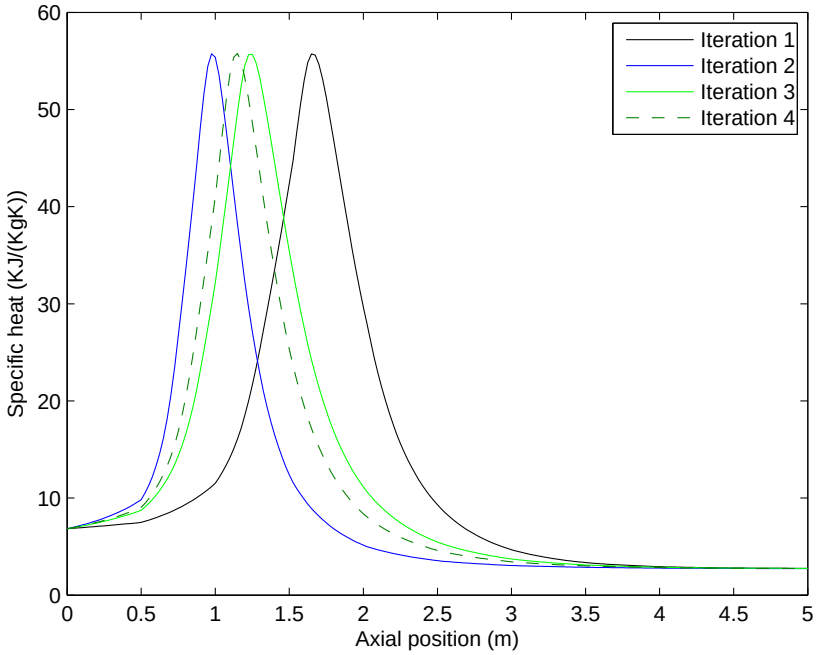


Figure 3.18 Specific-heat capacity at the first 4 iterations

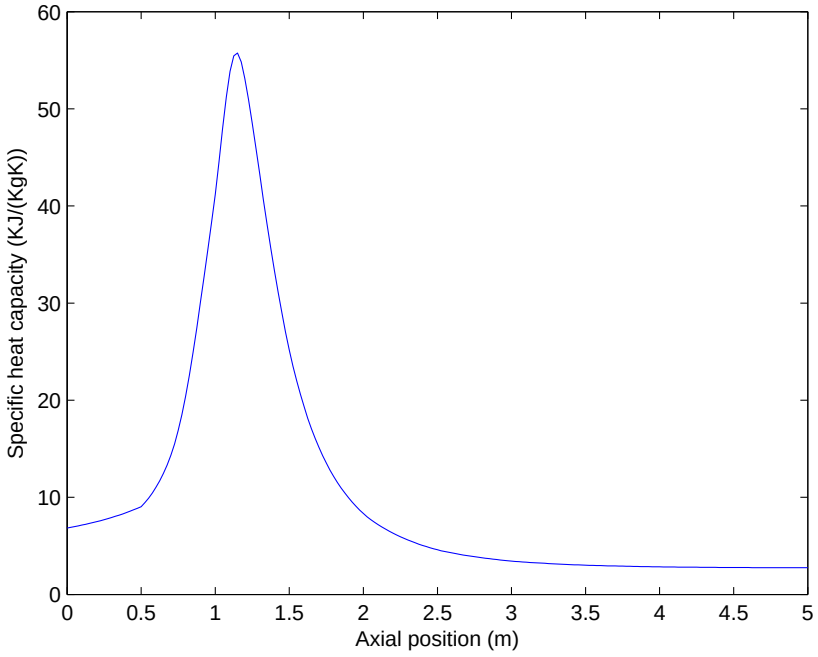


Figure 3.19 Specific-heat capacity at convergence

3.4.3 Heat-transfer coefficient

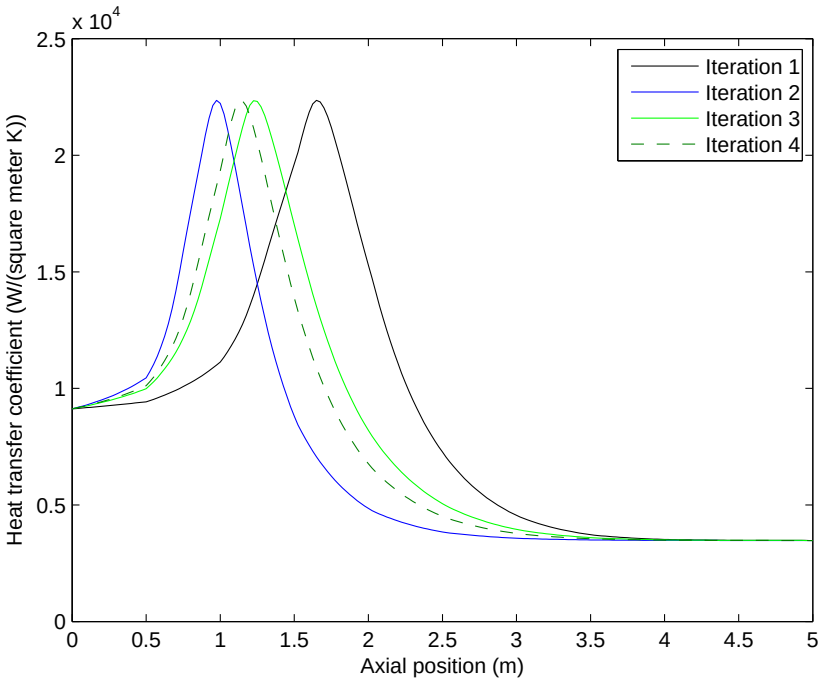


Figure 3.20 Heat transfer coefficient at the first 4 iterations

The position of the maximum of the heat-transfer coefficient coincides with that of the specific heat (Figures 3.18, 3.19, 3.20, and 3.21). Also, if a value of the heat-transfer coefficient is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the heat-transfer coefficient diminishes, from one iteration to the next one, as convergence is approached (Figure 3.21).

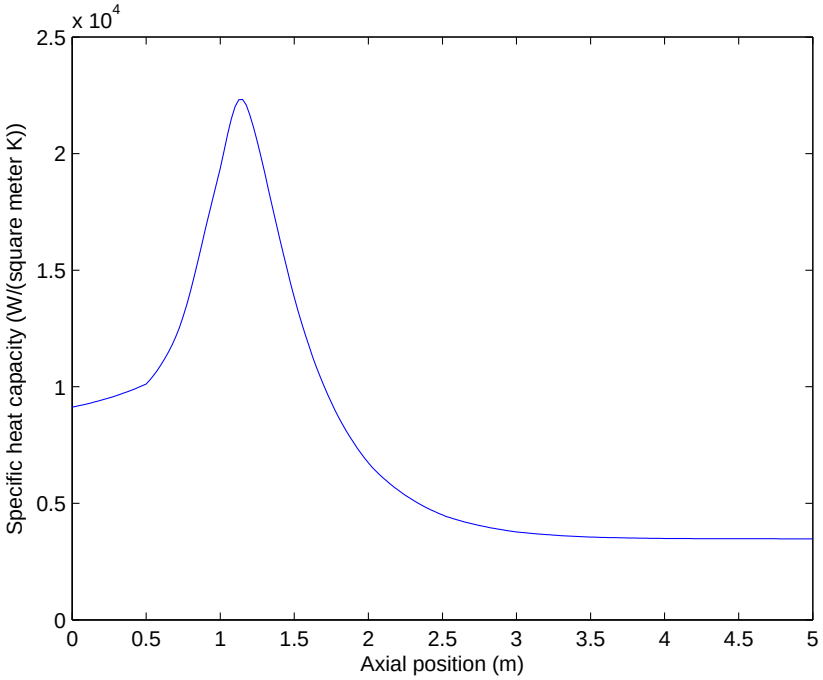


Figure 3.21 Heat-transfer coefficient at convergence

3.4.4 Coolant temperature

The coolant temperature increases rapidly at the approach of the peak of the heat-transfer coefficient (Figure 3.22); when the heat-transfer coefficient is maximum, the rate of heat transfer to the coolant is also maximum. Also, if a value of the coolant temperature is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant temperature diminishes, from one iteration to the next one, until convergence is reached (Figure 3.23). At convergence, the exit coolant temperature for Channel 5 is higher than the one for Channel 1; these are the consequences of the relatively higher power for Channel 5.

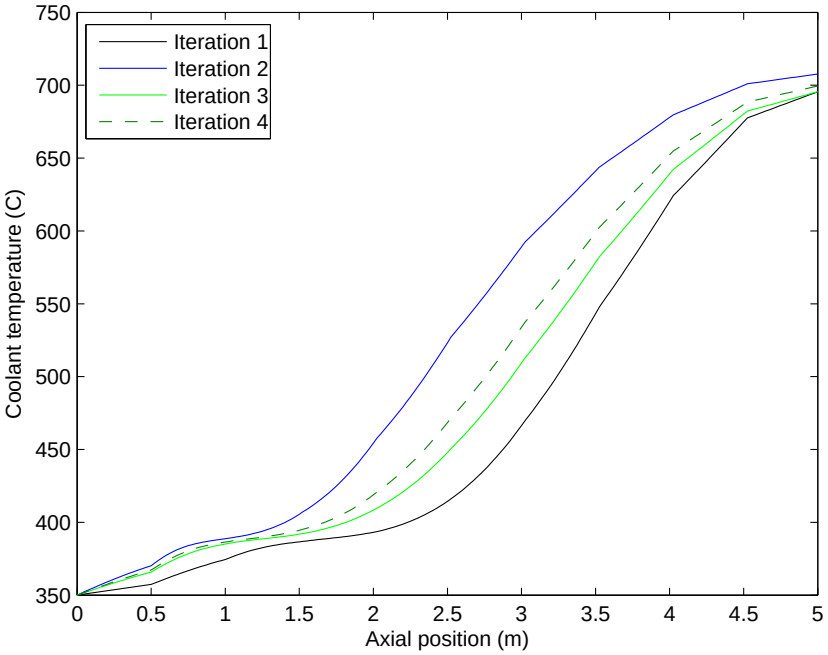


Figure 3.22 Coolant temperature at the first 4 iterations

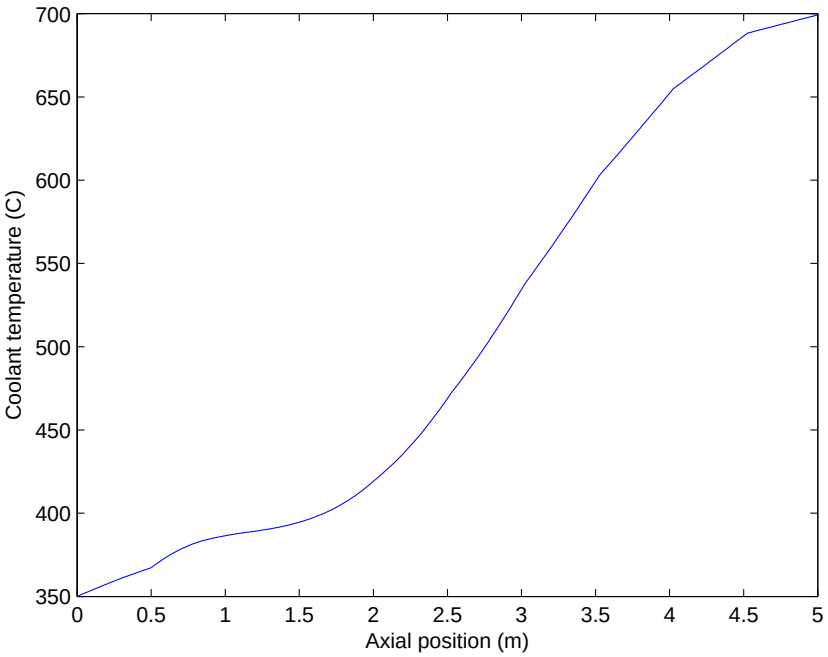


Figure 3.23 Coolant temperature at convergence

3.4.5 Coolant density

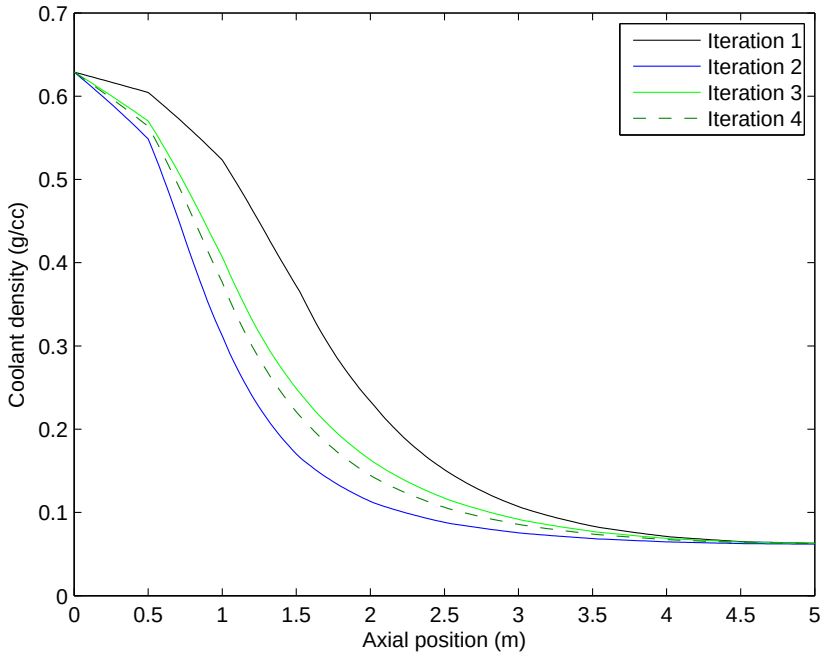


Figure 3.24 Coolant density at the first 4 iterations

In Figure 3.24, if a value of the coolant density is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant density diminishes, from one iteration to the next one. In Figure 3.25, the coolant density has an earlier drop and a lower exit value, compared to Figure 3.11.

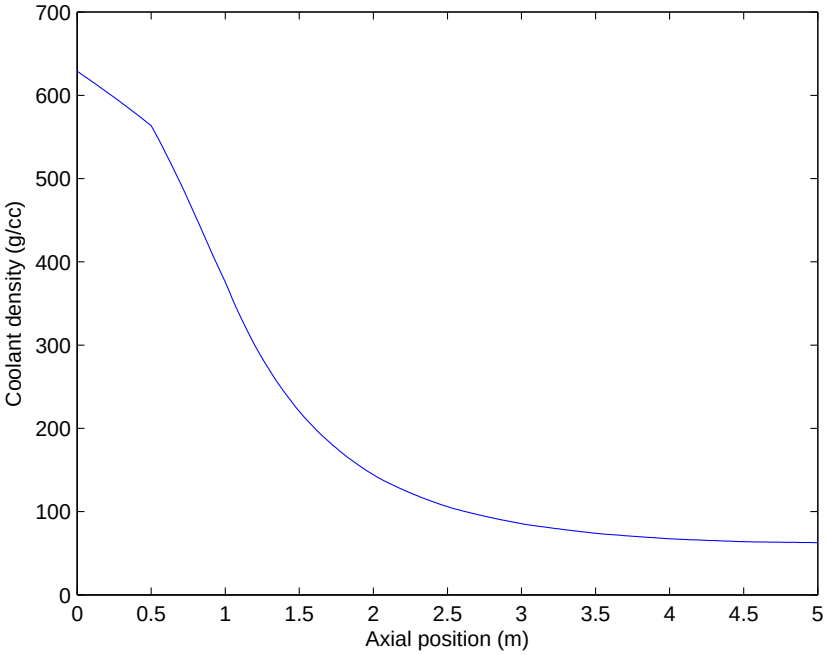


Figure 3.25 Coolant density at convergence

3.4.6 Pressure along the channel

In Figure 3.26, if one iteration under-estimates the pressure, the next one over-estimates it, and vice-versa. The process is repeated as the difference between successive values of the pressure diminishes, from one iteration to the next. In Figure 3.27, the pressure has an earlier drop and a lower exit value, compared to Figure 3.14.

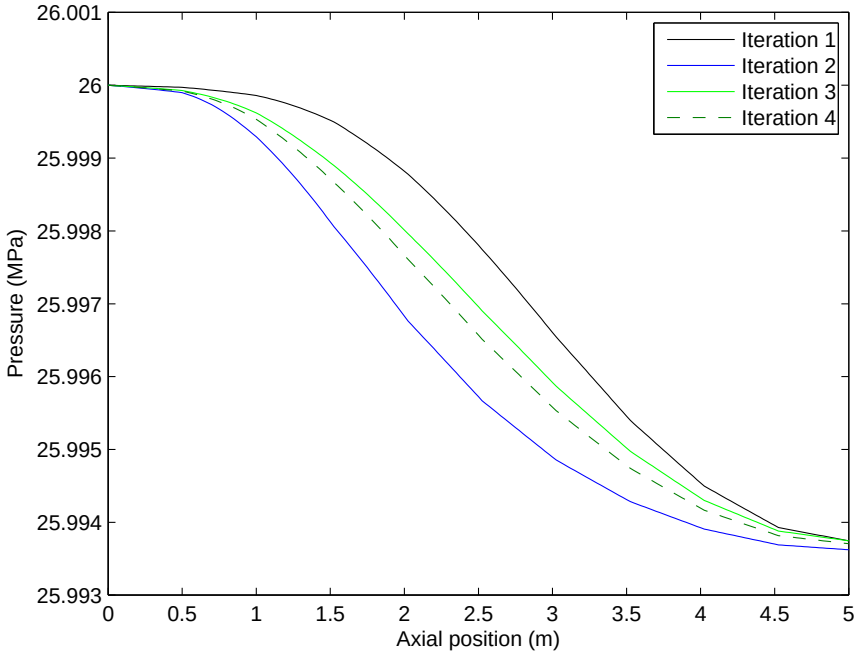


Figure 3.26 Pressure at the first 4 iterations

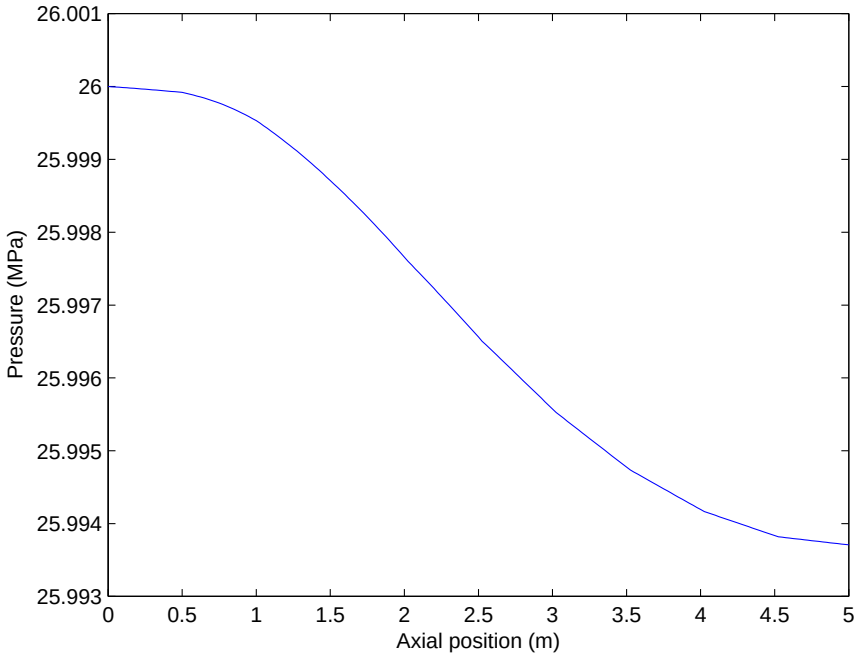


Figure 3.27 Pressure at convergence

3.4.7 Fuel and cladding temperatures

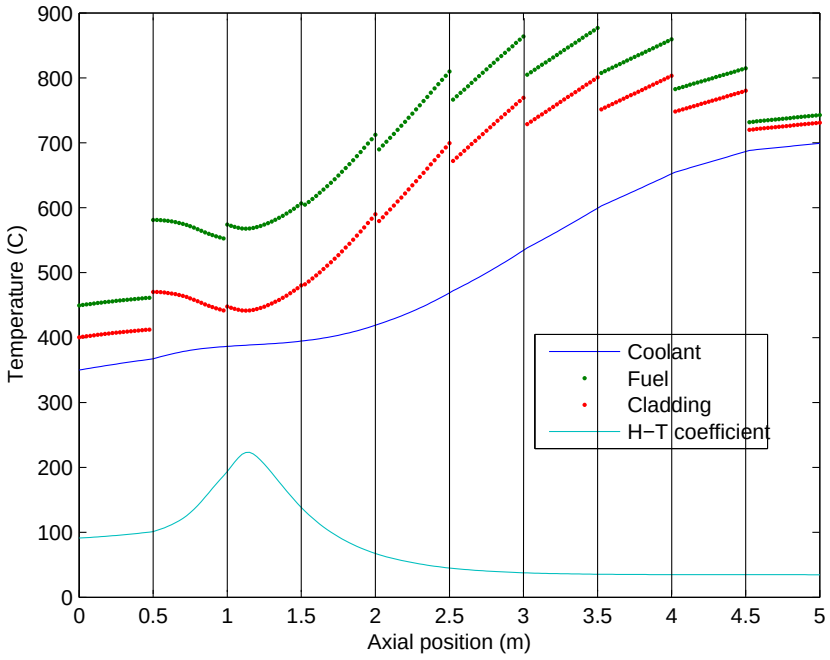


Figure 3.28 Data at convergence; heat-transfer coefficient in 100 $W \cdot (m^2 \cdot K)^{-1}$

In Figure 3.28, the fuel and cladding temperatures, for bundles next to the channel inlet, increase due to the low heat-transfer coefficient. Around the pseudo-critical point, they decrease with the rapid increase in the heat-transfer coefficient. Towards the end of the channel, they increase as a result of the low heat-transfer coefficient. Also, Channel 5 has higher fuel and cladding temperatures than Channel 1, and the center-line temperatures for the fuel and the cladding, in the case of Channel 5, may be lower than their fusion temperatures (3300 Celsius for the fuel and 850 Celsius for the cladding), since their radially-averaged values are below these limits.

3.5 Results for channel 10

3.5.1 Bundle power

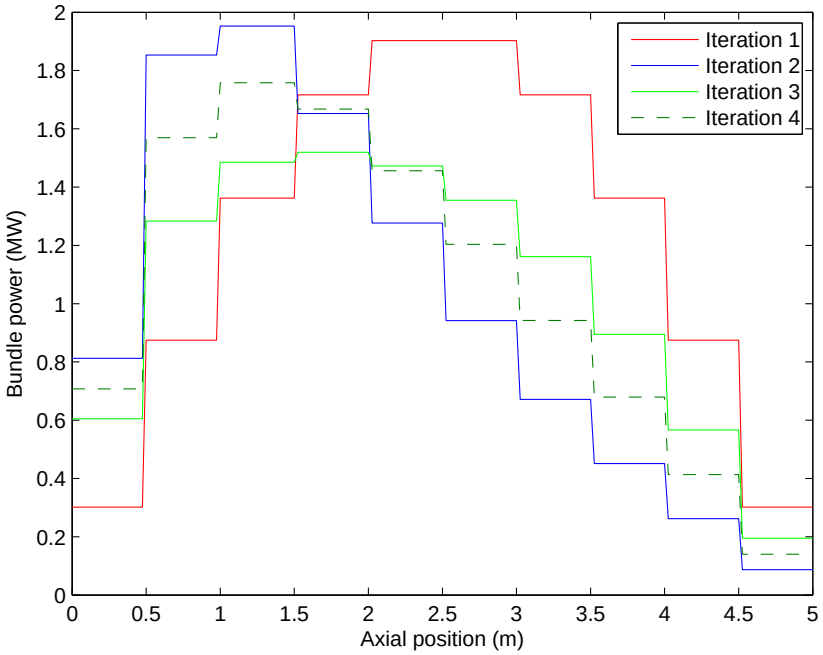


Figure 3.29 Bundle power at the first 4 iterations

In Figure 3.29, each iteration either over-estimates a bundle power, or under-estimates it. If a bundle power is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive bunder powers diminishes, as convergence is approached (Figure 3.30) Also, the location of the bundle-power peak oscillates during itetations. If it is under-estimated in one iteration, it will be over-estimated at the next iteration. This process is repeated until convergence is reached (Figure 3.30), at which point the bundle-power peak is located at the third bundle from the channel inlet. Furthermore, the value of the peak bundle power for Channel 10 is larger than that of Channel 5 since Channel 10 has a higher power.

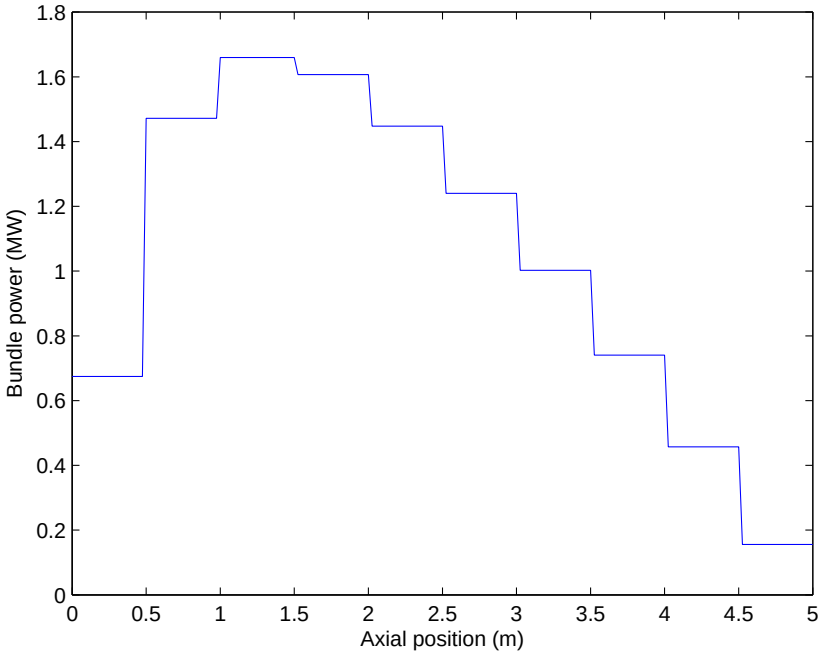


Figure 3.30 Bundle power at convergence

3.5.2 Specific-heat capacity

In Figure 3.31, each iteration either over-estimates the specific heat, or under-estimates it. If a value of the specific heat is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the specific heat diminishes, from one iteration to the next one. Moreover, each iteration either over-estimates the position of the pseudo-critical point, or under-estimates it. If an iteration under-estimates this position, the next iteration will over-estimate it, and vice-versa. This process is repeated as the difference between successive positions of the pseudo-critical point diminishes, from one iteration to the next one. At convergence, the peak of the specific-heat capacity of Channel 10 is shifted to the left of the one for Channel 5, due to the higher power of Channel 10 (Figures 3.19 and 3.32)

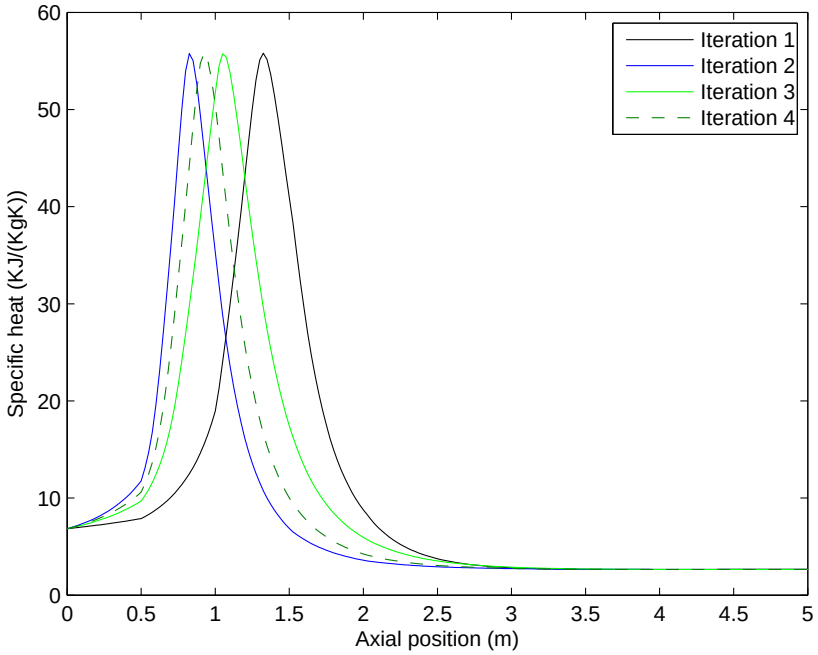


Figure 3.31 Specific-heat capacity at the first 4 iterations

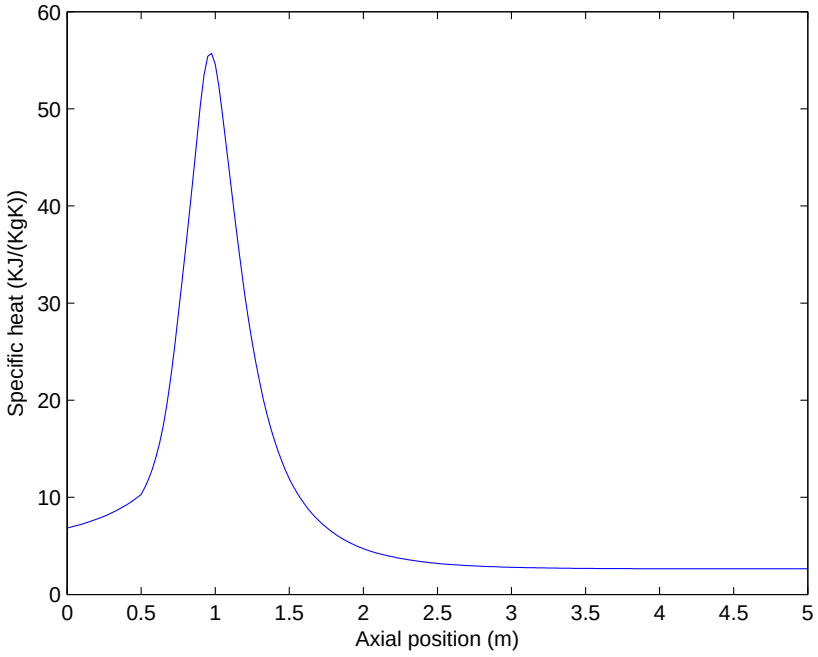


Figure 3.32 Specific-heat capacity at convergence

3.5.3 Heat-transfer coefficient

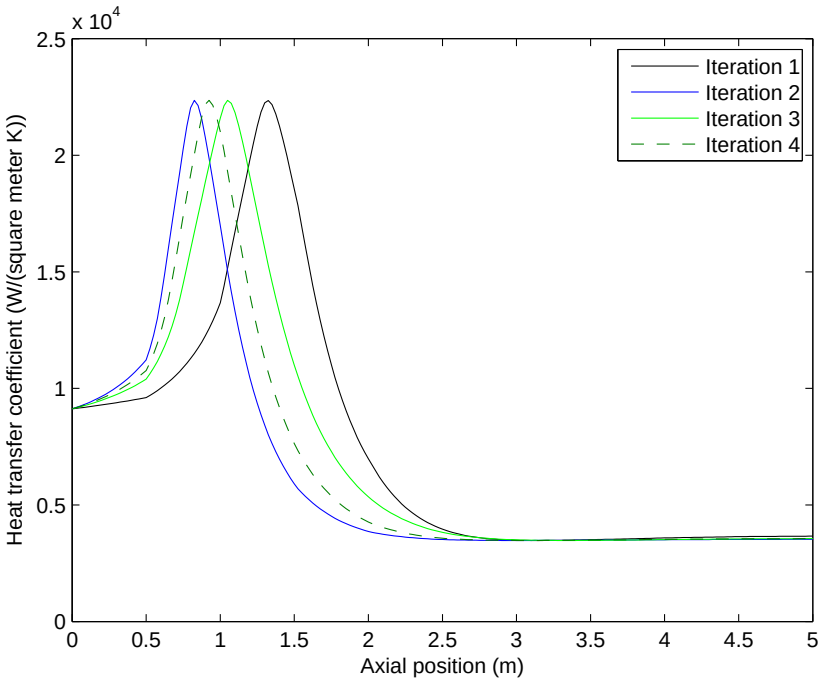


Figure 3.33 Heat-transfer coefficient at the first 4 iterations

In Figure 3.33, if a value of the heat-transfer coefficient is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the heat-transfer coefficient diminishes, from one iteration to the next, as convergence is approached (Figure 3.34).

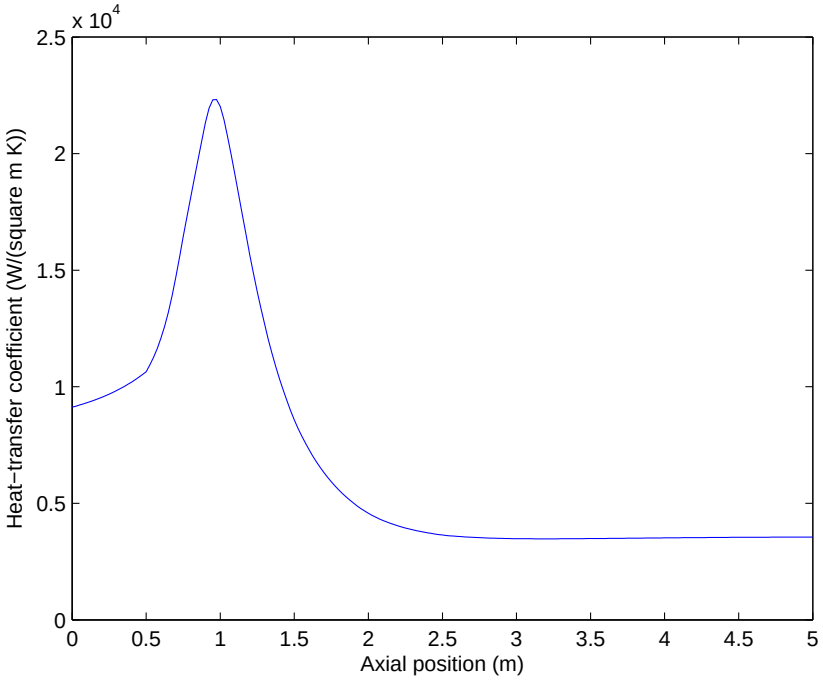


Figure 3.34 Heat-transfer coefficient at convergence

3.5.4 Coolant temperature

The coolant temperature increases rapidly at the approach of the peak of the heat-transfer coefficient (Figure 3.35); when the heat-transfer coefficient is maximum, the rate of heat transfer to the coolant is also maximum. Also, if a value of the coolant temperature is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant temperature diminishes, from one iteration to the next one, until convergence is reached (Figure 3.36). At convergence, the position of the initial temperature peak for Channel 10 is shifted to the left of the one for Channel 5. Also, the exit coolant temperature for Channel 10 is higher than the one for Channel 5; these are the consequences of the relatively higher power for Channel 10.

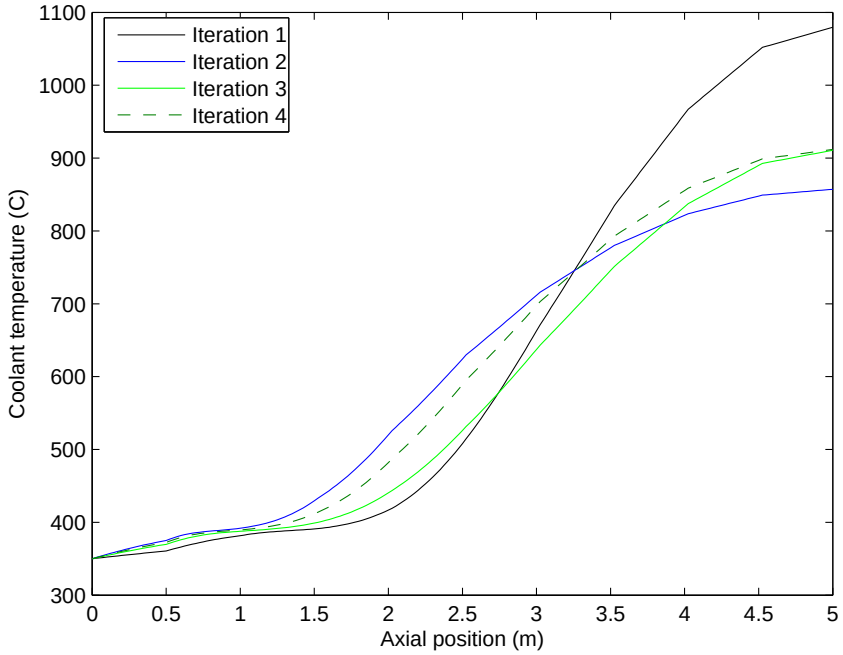


Figure 3.35 Coolant temperature at the first 4 iterations

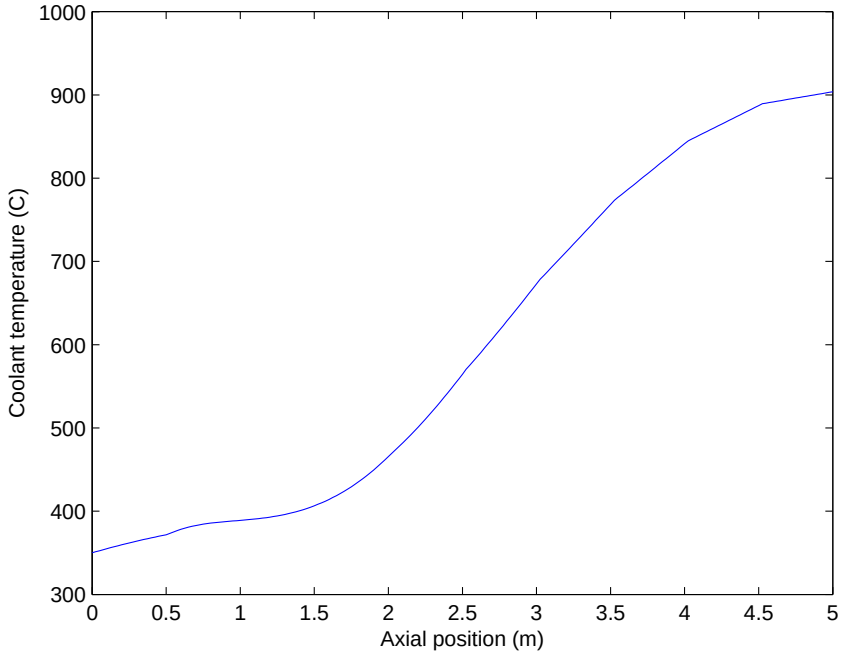


Figure 3.36 Coolant temperature at convergence

3.5.5 Coolant density

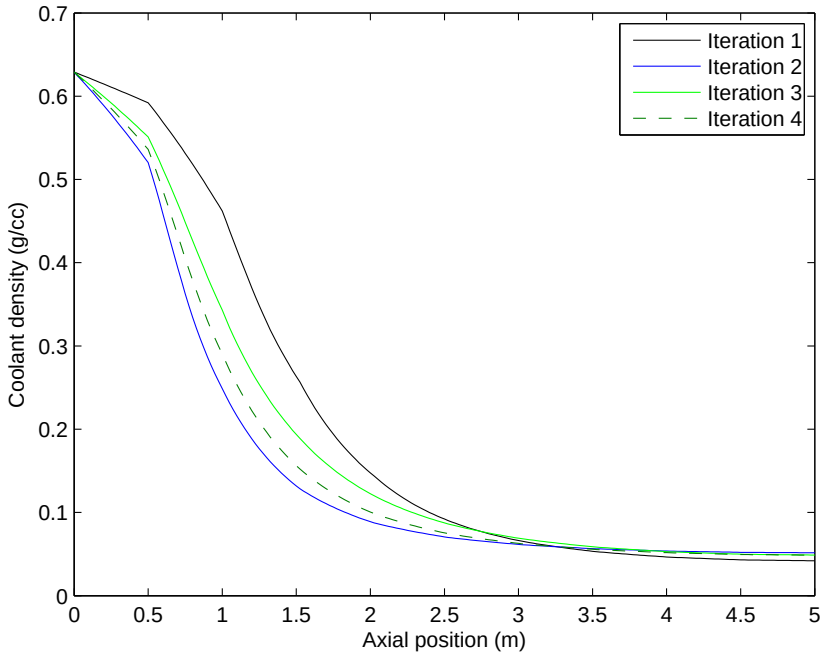


Figure 3.37 Coolant density at the first 4 iterations

In Figure 3.37, the location of the pseudo-critical point changes from one iteration to another, until convergence is reached. Moreover, if a value of the coolant density is under-estimated at an iteration, it will be over-estimated at the next iteration, and vice-versa. This process is repeated as the difference between successive values of the coolant density diminishes, from one iteration to the next. In Figure 3.38, the coolant density has an earlier drop and a lower exit value, compared to Figure 3.25.

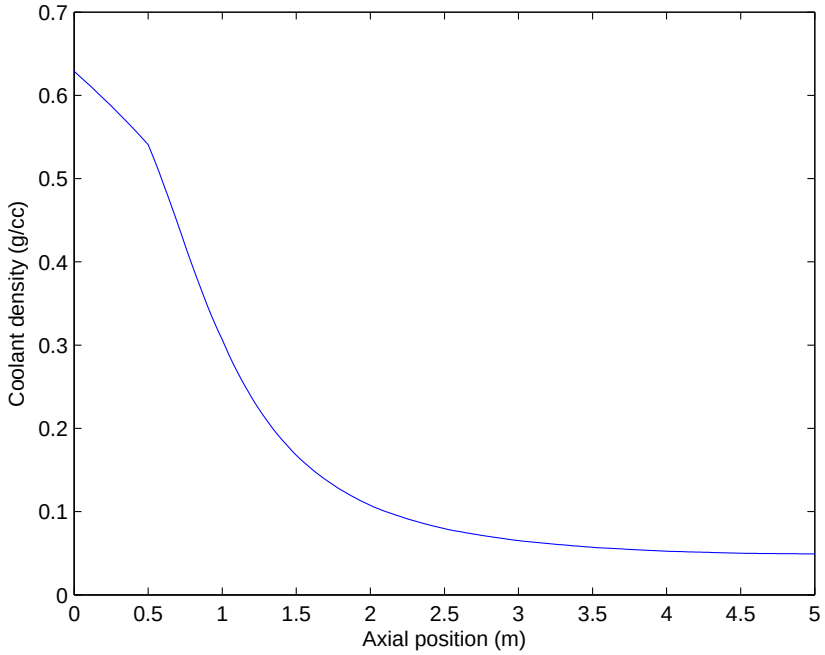


Figure 3.38 Coolant density at convergence

3.5.6 Pressure along the channel

In Figures 3.37 and 3.39, the higher the coolant-density gradient, the higher the coolant-pressure gradient. Also, if one iteration under-estimates the pressure, the next one over-estimates it, and vice-versa. This process is repeated until convergence is reached (Figure 3.40). In Figure 3.40, the pressure has an earlier drop and a lower exit value, compared to Figure 3.27.

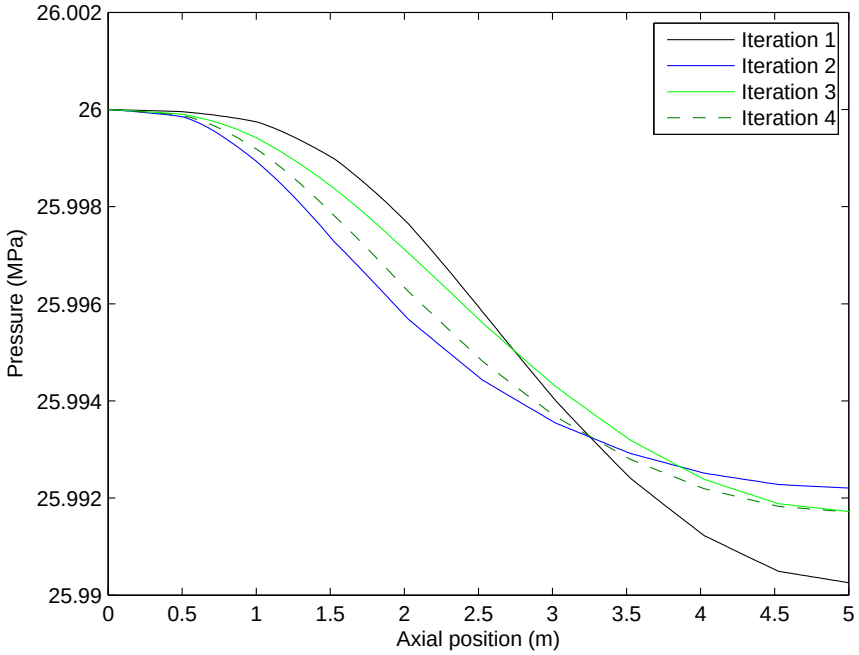


Figure 3.39 Pressure drop at the first 4 iterations

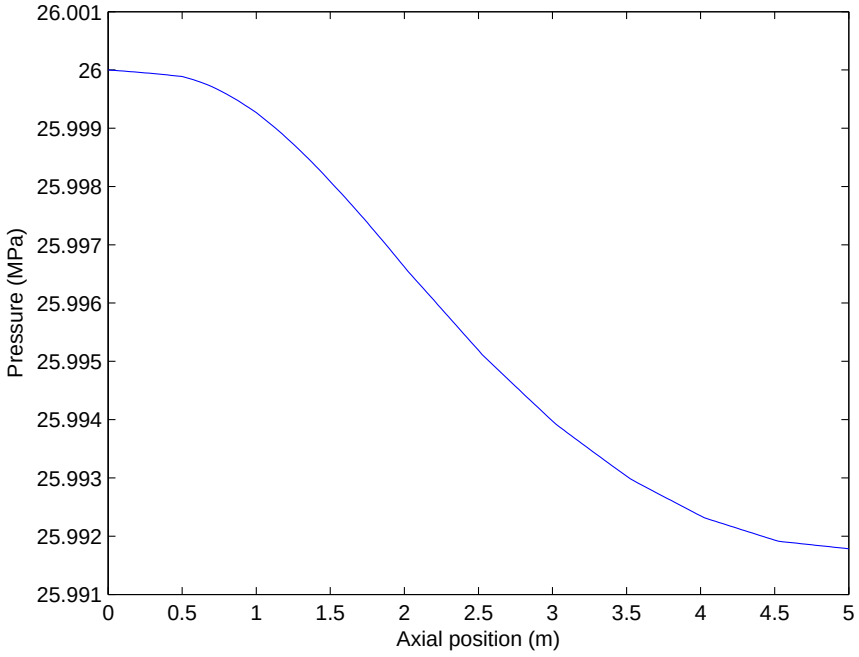


Figure 3.40 Pressure at convergence

3.5.7 Fuel and cladding temperatures

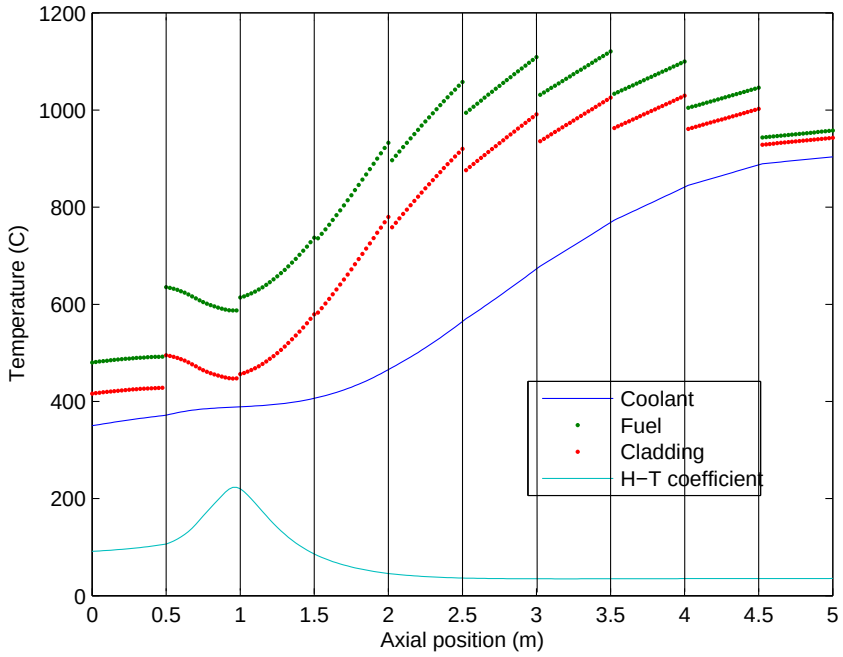


Figure 3.41 Data at convergence; heat-transfer coefficient in 100 W·(m^2· K)$^{-1}$

In Figure 3.41, the fuel and cladding temperatures, for bundles next to the channel inlet, increase due to the low heat-transfer coefficient. Around the pseudo-critical point, they decrease with the rapid increase in the heat-transfer coefficient. Towards the end of the channel, they increase as a result of the low heat-transfer coefficient. Also, Channel 10 has higher fuel and cladding temperatures than Channel 5, and the center-line temperature for the fuel, in the case of Channel 10, may be lower than its fusion temperature, since the calculated fuel temperatures are below this limit. However, for Channel 10, the cladding temperatures, of some bundles, exceed their allowable limit.

CHAPTER 4

CONCLUSION

The aim of this study has been to analyze the core-power distribution and the thermalhydraulics parameters of a CANDU SCWR, through the neutronics-thermalhydraulics coupling approach.

The core power obtained has a power peaking factor of 1.4. The bundle power distribution for all channels has a peak at the third bundle from the inlet, but the value of this peak increases with the channel power. The heat-transfer coefficient and the specific-heat capacity have a peak at the same location in a channel, and this location shifts toward the inlet as the channel power increases. The exit coolant temperature increases with the channel power, while the exit coolant density and pressure decrease with the channel power. Also, higher channel powers lead to higher fuel and cladding temperatures. Moreover, as the coupling method is applied, the effective multiplication factor and the values of thermalhydaulics parameters oscillate as they converge.

The results obtained agree with those predicted by AECL. In the latter case, a batch-3 refueling scheme was used, whereas this study was based on a core with fresh fuel only.

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APPENDIX A

DONJON input files

A.1 Main input file

```
 ************************************************************
*
* Input file :  SCWR_Core_54.x2m
* Purpose    :  Full core calculations
*
*
* Author     :  Pierre Adouki (2011/05)
*
*
* Note       :  Compatible with DONJON-3.02B
*
************************************************************

PROCEDURE    PGeoIns4Z PmacfixIns MapflInit ;
MODULE       TRIVAT: INIMAC: NEWMAC: LINKDS: TRIVAA: FLUD:
      GREP: END: FLXAXC: INIRES: REFRES: POWER: AFM:
      CRE: XSCONS: REFUEL: DELETE: UTL: THERMO: TRANS: ;
LINKED_LIST  Geometrie INDEX TRACK MACRO MACRO2 MACROFL
      DEVICE PROCEDE SYSTEM FLUX MAPFL TABFL
      peakFactor kEffective ;
SEQ_ASCII    flu mapfl map macro ;
STRING variableName ;
INTEGER iStep := 0 ;
REAL time finalTime step ;
EVALUATE time := 0. ;
EVALUATE finalTime := 1. ;
EVALUATE step := 1. ;

*----
```

```
*  fnat.cpo   : propriete cellule 2G fonction du burnup
*  rnat.cpo   : propriete reflecteur 2G independant du burnup
*  Bi         : Burnup of mix i  (MWj/T)
*----
SEQ_ASCII   FBMDAT  rnat.cpo macrofl map ;
LINKED_LIST FBMDATA NREFL ;
FBMDATA :=  FBMDAT ;
NREFL  := rnat.cpo   ;

REAL B1 B2 B3 keffInit keffFin deltaKeff tCool dCool tFuel ;

EVALUATE B1 := 0. ;
EVALUATE B2 := 0. ;
EVALUATE B3 := 0. ;

*----
*  Geometry definition
*--

INTEGER  Maxreg ;
Geometrie INDEX := PGeoIns4Z :: >>Maxreg<< ;
*--
*  Applying tracking
*--
TRACK := TRIVAT: Geometrie :: EDIT 0
  MAXR <<Maxreg>> MCFD 1 ;
*----
*  Macrolib definition
*----

 MAPFL := MapflInit :: <<B1>> <<B2>> <<B3>> ;

INDEX MAPFL := REFRES: INDEX MAPFL Geometrie ;

* MACRO := CRE: NREFL ::
* EDIT 0  NMIX 4
```

```
* READ COMPO NREFL MIX 4 'MIXTMOD    1'  ENDMIX
* ;

 MACRO := AFM: FBMDATA MAPFL ::
 MCR 4
 INFOR 'SCWR_DATABASE'
 DNAME 1 'MODFBMDATA'
 REFT 4  'MODFBMDATA'
 ;

MACROFL := AFM: FBMDATA MAPFL ::
  MAP
  INFOR 'SCWR_DATABASE'
  DNAME 3 'FULFBMDATA' 'FULFBMDATA' 'FULFBMDATA'
  REFT 1 'FULFBMDATA' 2 'FULFBMDATA' 3 'FULFBMDATA'
  BORON 0.0
;

*--
* Creating extended macrolib
*--
MACRO2 := INIMAC: INDEX MACRO MACROFL ;

*----
*  Flux calculations
*----
SYSTEM := TRIVAA: MACRO2 TRACK :: EDIT 0 ;
FLUX := FLUD: SYSTEM TRACK ::  EDIT 0
;

MAPFL := FLXAXC: MAPFL FLUX TRACK INDEX ::
FLUX-AV ;

MAPFL := POWER: MAPFL MACROFL ::
EDIT 3 POWER 2540. ;
```

```
MAPFL := THERMO: MAPFL
;

GREP: FLUX :: GETVAL K-EFFECTIVE 1 >>keffInit<< ;
EVALUATE keffFin := 0.0 ;
EVALUATE deltaKeff := keffInit keffFin - ABS ;
ECHO "k-effective" keffInit ":" ;

WHILE deltaKeff 1.0E-5 >
DO
 EVALUATE keffFin := keffInit ;

*-------CREATING NEW FUEL MACROLIB-----------------------*
 MACROFL := DELETE: MACROFL ;
 MACROFL := AFM: FBMDATA MAPFL ::
  MAP
  INFOR 'SCWR_DATABASE'
  DNAME 3 'FULFBMDATA' 'FULFBMDATA' 'FULFBMDATA'
  REFT 1 'FULFBMDATA' 2 'FULFBMDATA' 3 'FULFBMDATA'
  BORON 0.0
  ;
*-----------------------------------------------------*
*--
*-----CREATING NEW EXTENDED MACROLIB-------------------*
 MACRO2 := DELETE: MACRO2 ;
 MACRO2 := INIMAC: INDEX MACRO MACROFL ;
*-----------------------------------------------------*

*------CALCULATING NEW FLUX-----------------------------*
 SYSTEM FLUX := DELETE: SYSTEM FLUX ;
 SYSTEM := TRIVAA: MACRO2 TRACK :: EDIT 0 ;

 FLUX := FLUD: SYSTEM TRACK ::  EDIT 0
 ;

 MAPFL := FLXAXC: MAPFL FLUX TRACK INDEX ::
```

```
  FLUX-AV ;

*-----CALCULATING NEW POWER-------------------------------*

 MAPFL := POWER: MAPFL MACROFL ::
  EDIT 3 POWER 2540.0 ;
*------------------------------------------------------*

*-----CALCULATING NEW THERMODYNAMIC VALUES---------------*
 MAPFL := THERMO: MAPFL
 ;
*------------------------------------------------------*
 GREP: FLUX :: GETVAL K-EFFECTIVE 1 >>keffInit<< ;

 EVALUATE deltaKeff := keffInit keffFin - ABS ;
 ECHO "k-effective" keffInit ":" ;
ENDWHILE ;

*-------LOCA POWER CALCULATIONS---------------------------*


*------------------------------------------------------*
MAPFL := TRANS: MAPFL ;

*-------CREATING NEW FUEL MACROLIB-----------------------*
 MACROFL := DELETE: MACROFL ;
 MACROFL := AFM: FBMDATA MAPFL ::
  MAP
  INFOR 'SCWR_DATABASE'
  DNAME 3 'FULFBMDATA' 'FULFBMDATA' 'FULFBMDATA'
  REFT 1 'FULFBMDATA' 2 'FULFBMDATA' 3 'FULFBMDATA'
  BORON 0.0
  ;

*------------------------------------------------------*
*--
```

```
*-----CREATING NEW EXTENDED MACROLIB----------------------*
 MACRO2 := DELETE: MACRO2 ;
 MACRO2 := INIMAC: INDEX MACRO MACROFL ;
*-------------------------------------------------------*

*------CALCULATING NEW FLUX-------------------------------*
 SYSTEM FLUX := DELETE: SYSTEM FLUX ;
 SYSTEM := TRIVAA: MACRO2 TRACK :: EDIT 0 ;

 FLUX := FLUD: SYSTEM TRACK ::  EDIT 0
 ;

 MAPFL := FLXAXC: MAPFL FLUX TRACK INDEX ::
  FLUX-AV ;

*-----CALCULATING NEW POWER-------------------------------*

 MAPFL := POWER: MAPFL MACROFL ::
  EDIT 3 POWER 2540.0 ;
*-------------------------------------------------------*
*----
* Exporter
*----
 mapfl := MAPFL ;
 macrofl := MACROFL ;
 END: ;
QUIT .
```

A.2 Procedures

A.2.1 Procedure PGeoIns4Z

```
*----
* PROCEDURE:  PGeoIns4Z
* USAGE:      Geometrie CANDU 6 avec 4 zones de burnup
* AUTHOR:     E.Varin (1996/02/01)
```

```
*             B. Dionne (2001/03/04) (pour cours ENE6209)
*             R. Chambon (2010/03/16) (pour cours ENE6203)
*             G. Marleau (2010/03/16) (pour cours ENE6203)
*             P. Adouki  (May 2011)
*  Appel:
*  Geometrie INDEX := PGeoIns4Z :: >>Maxreg<< ;
*
*
*
*----
PARAMETER Geometrie INDEX ::
      ::: LINKED_LIST Geometrie INDEX ; ;
MODULE END: GEOD: USPLIT: ;
LINKED_LIST GEOM ;
INTEGER Maxreg := 27700 ;
 :: <<Maxreg>> ;
*----
* Definition de la gemometrie a 3 zones
*----
 GEOM := GEOD: :: CAR3D 24 24 10
   EDIT 0
   X- ZERO   X+ ZERO
   Y- ZERO   Y+ ZERO
   Z- ZERO   Z+ ZERO

  MIX

  PLANE 1

     0 0 0 0 0 0 0 4 4 4 4 4  4 4 4 4 4 0 0 0 0 0 0 0
     0 0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0
     0 0 0 0 0 4 4 1 2 1 3 1  1 3 1 2 1 4 4 0 0 0 0 0
     0 0 0 0 4 4 1 2 1 3 1 3  3 1 3 1 2 1 4 4 0 0 0 0
     0 0 0 4 4 3 3 1 3 1 3 1  1 3 1 3 1 3 3 4 4 0 0 0
     0 0 4 4 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 4 4 0 0
     0 4 4 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 4 4 0
```

```
0 4 4 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 4 4 0
4 4 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 4 4
4 4 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 4 4
4 4 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 4 4
4 4 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 4 4

4 4 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 4 4
4 4 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 4 4
4 4 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 4 4
4 4 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 4 4
0 4 4 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 4 4 0
0 4 4 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 4 4 0
0 0 4 4 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 4 4 0 0
0 0 0 4 4 3 3 1 3 1 3 1  1 3 1 3 1 3 3 4 4 0 0 0
0 0 0 0 4 4 1 2 1 3 1 3  3 1 3 1 2 1 4 4 0 0 0 0
0 0 0 0 0 4 4 1 2 1 3 1  1 3 1 2 1 4 4 0 0 0 0 0
0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0
0 0 0 0 0 0 0 4 4 4 4 4  4 4 4 4 4 0 0 0 0 0 0 0
```

PLANE 3

```
0 0 0 0 0 0 0 4 4 4 4 4  4 4 4 4 4 0 0 0 0 0 0 0
0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0
0 0 0 0 0 4 4 1 2 1 3 1  1 3 1 2 1 4 4 0 0 0 0 0
0 0 0 0 4 4 1 2 1 3 1 3  3 1 3 1 2 1 4 4 0 0 0 0
0 0 0 4 4 3 3 1 3 1 3 1  1 3 1 3 1 3 3 4 4 0 0 0
0 0 4 4 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 4 4 0 0
0 4 4 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 4 4 0
0 4 4 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 4 4 0
4 4 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 4 4
4 4 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 4 4
4 4 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 4 4
4 4 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 4 4

4 4 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 4 4
```

```
   4 4 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 4 4
   4 4 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 4 4
   4 4 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 4 4
   0 4 4 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 4 4 0
   0 4 4 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 4 4 0
   0 0 4 4 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 4 4 0 0
   0 0 0 4 4 3 3 1 3 1 3 1  1 3 1 3 1 3 3 4 4 0 0 0
   0 0 0 0 4 4 1 2 1 3 1 3  3 1 3 1 2 1 4 4 0 0 0 0
   0 0 0 0 0 4 4 1 2 1 3 1  1 3 1 2 1 4 4 0 0 0 0 0
   0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0
   0 0 0 0 0 0 0 4 4 4 4 4  4 4 4 4 4 0 0 0 0 0 0 0

 PLANE 2  SAME 1
 PLANE 4  SAME 3
 PLANE 5  SAME 3
 PLANE 6  SAME 3
 PLANE 7  SAME 3
 PLANE 8  SAME 3
 PLANE 9  SAME 1
 PLANE 10 SAME 1

 MESHX  0.0 41.9 65.375 90.375 115.375 140.375 165.375 190.375
        215.375 240.375 265.375 290.375 315.375 340.375 365.375
        390.375 415.375 440.375 465.375 490.375 515.375 540.375
        565.375 588.85 630.75
 MESHY  0.0 41.9 65.375 90.375 115.375 140.375 165.375 190.375
        215.375 240.375 265.375 290.375 315.375 340.375 365.375
        390.375 415.375 440.375 465.375 490.375 515.375 540.375
        565.375 588.85 630.75
 MESHZ  0.0 50.0 100.0 150.0 200.0 250.0 300.0 350.0
        400.0 450.0 500.0
;


Geometrie INDEX := USPLIT: GEOM :: MAXR <<Maxreg>> ;
```

```
 END: ;

QUIT "LIST" .
```

A.2.2 Procedure Pmacfix

```
!****************************************************************************
!*                                                                          **
!* PROCEDURE:  Pmacfix                                                      **
!* USAGE:      Macrolib construction Gentilly2 reactor from DRAGON          **
!*             properties for fixed material (devices) and reflector        **
!* AUTHOR:     E.Varin (96/02/12)                                           **
!* Modified:   W. SHEN (97/10/10)                                           **
!*             B. Dionne (01/03/04) (pour cours ENE6209)                    **
!*             R. Chambon (10/03/15) (pour calcul instantane 4 zones)       **
!*             P.Adouki (May 2011) for Candu SCWR                           **
!* CALL:                                                                    **
!*                                                                          **
!*  MACRO := PmacfixIns  ;                                                  **
!*                                                                          **
!*                                                                          **
!* NOTES:                                                                   **
!*                                                                          **
!*    All the sequential ASCII files are exported COMPO files               **
!*    and must have the names and directory hierarchy as used               **
!*    in the calling to CRE: module                                         **
!*                                                                          **
!*    Check also mixture numbers with reference to geometry                 **
!*    construction  and device description                                  **
!*                                                                          **
!****************************************************************************

 PARAMETER MACRO NFUEL NREFL  ::
   ::: LINKED_LIST MACRO NFUEL NREFL ; ;

 MODULE CRE: END: ;
```

```
!* Declaration des variables
!**************************
 REAL B1 B2 B3 ;
 :: >>B1<< >>B2<< >>B3<< ;


!* Generation des melanges (sections efficaces macroscopiques)
!************************************************************
 MACRO := CRE: NFUEL NREFL ::
   EDIT 0  NMIX 4
   READ    COMPO NREFL   MIX    4      'MIXTMOD    1'  ENDMIX

           COMPO NFUEL   MIX    1      'MELANGE    1'
                     I-BURNUP <<B1>>                    ENDMIX
                         MIX    2      'MELANGE    1'
                     I-BURNUP <<B2>>                    ENDMIX
                         MIX    3      'MELANGE    1'
                     I-BURNUP <<B3>>                 ENDMIX

 ;

END: ;

QUIT "LIST" .
```

A.2.3 Procedure MapflInit

```
************************************************************
*
* Input file :  MapflInit.c2m
* Purpose    :  Initialization of fuel map
*
*
* Author     :  Pierre Adouki (2011/05)
*
```

```
*
* Note       :  Compatible with DONJON-3.02B
*
*****************************************************************


PARAMETER  MAPFL ::
   ::: LINKED_LIST MAPFL ; ;

MODULE INIRES: END: ;

REAL B1 B2 B3 ;

:: >>B1<< >>B2<< >>B3<< ;

MAPFL := INIRES: :: NBUND 10 NCHAN 336 NZONE 3 NGRP 2 IMOD 4
    ::: GEOD: CAR3D 24 24 10
EDIT 0
   X- ZERO   X+ ZERO
   Y- ZERO   Y+ ZERO
   Z- ZERO   Z+ ZERO

  MIX
  PLANE 1


     0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
     0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
     0 0 0 0 0 0 0 1 2 1 3 1  1 3 1 2 1 0 0 0 0 0 0 0
     0 0 0 0 0 0 1 2 1 3 1 3  3 1 3 1 2 1 0 0 0 0 0 0
     0 0 0 0 0 3 3 1 3 1 3 1  1 3 1 3 1 3 3 0 0 0 0 0
     0 0 0 0 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 0 0 0 0
     0 0 0 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 0 0 0
     0 0 0 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 0 0 0
     0 0 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 0 0
     0 0 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 0 0
```

```
0 0 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 0 0
0 0 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 0 0

0 0 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 0 0
0 0 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 0 0
0 0 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 0 0
0 0 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 0 0
0 0 0 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 0 0 0
0 0 0 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 0 0 0
0 0 0 0 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 0 0 0 0
0 0 0 0 0 3 3 1 3 1 3 1  1 3 1 3 1 3 3 0 0 0 0 0
0 0 0 0 0 0 1 2 1 3 1 3  3 1 3 1 2 1 0 0 0 0 0 0
0 0 0 0 0 0 0 1 2 1 3 1  1 3 1 2 1 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
```

PLANE 3

```
0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 1 2 1 3 1  1 3 1 2 1 0 0 0 0 0 0 0
0 0 0 0 0 0 1 2 1 3 1 3  3 1 3 1 2 1 0 0 0 0 0 0
0 0 0 0 0 3 3 1 3 1 3 1  1 3 1 3 1 3 3 0 0 0 0 0
0 0 0 0 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 0 0 0 0
0 0 0 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 0 0 0
0 0 0 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 0 0 0
0 0 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 0 0
0 0 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 0 0
0 0 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 0 0
0 0 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 0 0

0 0 2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2 0 0
0 0 3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3 0 0
0 0 1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1 0 0
```

```
   0 0 2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2 0 0
   0 0 0 3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3 0 0 0
   0 0 0 1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1 0 0 0
   0 0 0 0 1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1 0 0 0 0
   0 0 0 0 0 3 3 1 3 1 3 1  1 3 1 3 1 3 3 0 0 0 0 0
   0 0 0 0 0 0 1 2 1 3 1 3  3 1 3 1 2 1 0 0 0 0 0 0
   0 0 0 0 0 0 0 1 2 1 3 1  1 3 1 2 1 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0
   0 0 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0 0 0


PLANE 2  SAME 1
PLANE 4  SAME 3
PLANE 5  SAME 3
PLANE 6  SAME 3
PLANE 7  SAME 3
PLANE 8  SAME 3
PLANE 9  SAME 1
PLANE 10 SAME 1

MESHX  0.0 41.9 65.375 90.375 115.375 140.375 165.375 190.375
215.375 240.375 265.375 290.375 315.375 340.375 365.375
390.375 415.375 440.375 465.375 490.375 515.375 540.375
565.375 588.85 630.75
MESHY  0.0 41.9 65.375 90.375 115.375 140.375 165.375 190.375
215.375 240.375 265.375 290.375 315.375 340.375 365.375
390.375 415.375 440.375 465.375 490.375 515.375 540.375
565.375 588.85 630.75
MESHZ  0.0 50.0 100.0 150.0 200.0 250.0 300.0 350.0
400.0 450.0 500.0
;

NXNAME '1' '2' '3' '4' '5' '6' '7' '8' '9' '10' '11' '12' '13'
'14' '15' '16' '17' '18' '19' '20' '21' '22' '23' '24'
NYNAME 'A' 'B' 'C' 'D' 'E' 'F' 'G' 'H' 'I' 'J' 'K' 'L' 'M' 'N'
'O' 'P' 'Q' 'R' 'S' 'T' 'Q' 'V' 'W' 'X'
```

BURN-ZONE

```
              1 2 1 3 1  1 3 1 2 1
            1 2 1 3 1 3  3 1 3 1 2 1
          3 3 1 3 1 3 1  1 3 1 3 1 3 3
        1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1
      1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1
      3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3
    2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2
    1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1
    3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3
    2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2
    2 3 1 2 2 2 3 2 2 2  2 2 2 3 2 2 2 1 3 2
    3 1 3 2 2 3 1 2 3 2  2 3 2 1 3 2 2 3 1 3
    1 2 1 3 1 3 2 2 2 2  2 2 2 2 3 1 3 1 2 1
    2 1 3 1 3 1 3 2 1 3  3 1 2 3 1 3 1 3 1 2
      3 1 2 2 3 1 3 3 1  1 3 3 1 3 2 2 1 3
      1 3 1 3 1 2 1 2 3  3 2 1 2 1 3 1 3 1
        1 3 1 2 2 3 2 2  2 2 3 2 2 1 3 1
          3 3 1 3 1 3 1  1 3 1 3 1 3 3
            1 2 1 3 1 3  3 1 3 1 2 1
              1 2 1 3 1  1 3 1 2 1
```

CPPF-ZONE

```
              1 1 1 1 1  1 1 1 1 1
            1 1 1 1 1 1  1 1 1 1 1 1
          1 1 1 1 1 1 1  1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1  1 1 1 1 1 1 1
            1 1 1 1 1 1  1 1 1 1 1 1
              1 1 1 1 1  1 1 1 1 1
```

```
        1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1  1 1 1 1 1 1 1
            1 1 1 1 1 1  1 1 1 1 1 1
              1 1 1 1 1  1 1 1 1 1
                1 1 1 1  1 1 1 1

  BURNUP-ZC <<B1>> <<B2>> <<B3>>

;

MAPFL := INIRES: MAPFL ::
*WEIGHT 19.36
WEIGHT 31.61
BURN-FUEL
  <<B1>>  <<B2>>  <<B1>>  <<B3>>  <<B1>>  <<B1>>  <<B3>>  <<B1>>
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  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B2>>  <<B1>>  <<B3>>  <<B3>>
  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B1>>  <<B3>>  <<B1>>
  <<B3>>  <<B1>>  <<B3>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B2>>
  <<B2>>  <<B3>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>  <<B3>>  <<B2>>
  <<B2>>  <<B1>>  <<B3>>  <<B1>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>
  <<B1>>  <<B2>>  <<B1>>  <<B2>>  <<B3>>  <<B3>>  <<B2>>  <<B1>>
  <<B2>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>
  <<B2>>  <<B2>>  <<B3>>  <<B1>>  <<B3>>  <<B3>>  <<B1>>  <<B1>>
  <<B3>>  <<B3>>  <<B1>>  <<B3>>  <<B2>>  <<B2>>  <<B1>>  <<B3>>
  <<B2>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B2>>
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  <<B1>>  <<B3>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>
  <<B2>>  <<B2>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B2>>  <<B1>>
  <<B3>>  <<B1>>  <<B3>>  <<B2>>  <<B2>>  <<B3>>  <<B1>>  <<B2>>
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  <<B2>>  <<B2>>  <<B3>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>  <<B2>>
```

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<<B2>> <<B2>> <<B2>> <<B2>> <<B2>> <<B2>> <<B3>> <<B1>>
<<B3>> <<B1>> <<B2>> <<B1>> <<B2>> <<B1>> <<B3>> <<B1>>
<<B3>> <<B1>> <<B3>> <<B2>> <<B1>> <<B3>> <<B3>> <<B1>>
<<B2>> <<B3>> <<B1>> <<B3>> <<B1>> <<B3>> <<B1>> <<B2>>
<<B3>> <<B1>> <<B2>> <<B2>> <<B3>> <<B1>> <<B3>> <<B3>>
<<B1>> <<B1>> <<B3>> <<B3>> <<B1>> <<B3>> <<B2>> <<B2>>
<<B1>> <<B3>> <<B1>> <<B3>> <<B1>> <<B3>> <<B1>> <<B2>>
<<B1>> <<B2>> <<B3>> <<B3>> <<B2>> <<B1>> <<B2>> <<B1>>
<<B3>> <<B1>> <<B3>> <<B1>> <<B1>> <<B3>> <<B1>> <<B2>>
<<B2>> <<B3>> <<B2>> <<B2>> <<B2>> <<B2>> <<B3>> <<B2>>
<<B2>> <<B1>> <<B3>> <<B1>> <<B3>> <<B3>> <<B1>> <<B3>>

```
  <<B1>>  <<B3>>  <<B1>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>  <<B1>>
  <<B3>>  <<B3>>  <<B1>>  <<B2>>  <<B1>>  <<B3>>  <<B1>>  <<B3>>
  <<B3>>  <<B1>>  <<B3>>  <<B1>>  <<B2>>  <<B1>>  <<B1>>  <<B2>>
  <<B1>>  <<B3>>  <<B1>>  <<B1>>  <<B3>>  <<B1>>  <<B2>>  <<B1>>
;

END: ;

QUIT "LIST" .
```

APPENDIX B

DRAGON input files for reactivity-coefficient calculations

B.1 Main input file

```
*DECK CalculCellule2D
*--------------------
*  Nom           : CalculCellule2D.x2m
*  Utilisation   : Fichier d'entree pour le calcul de la cellule 2D du SCWR
*  Auteur        : G. Harrisson
*  Date          : 2011/05/02
*  Modifier      : Mai 2011 par P. Adouki
*-------------------------------------------------------------------------------
*Definir les modules utilises, les procedures appelees et les structures de donnees des
*-------------------------------------------------------------------------------
MODULE      DELETE: END: PSP: ;
PROCEDURE   SCWRLib1 SCWRGeo2D SCWRTrack2D EvolRefB ;
LINKED_LIST GeoAutoPro GeoFlux  VolumAutoPro VolumFlux ;
XSM_FILE    BiblioInt ConcIso Resultats  ;
SEQ_ASCII   Res.res DBRef  PSGEO PSGEOAuto.ps PSGEOFlux.ps ;
SEQ_BINARY  LignAutoPro LignFlux ;
REAL        TCalo DCalo DCaloIsol Bundle_Power TFuel ;
EVALUATE Bundle_Power := 24.13 ;
*-------------------------------------------------------------------------------
*Definir les geometries de base pour le calcul de l'autoprotection des resonances et pou
*-------------------------------------------------------------------------------
GeoAutoPro GeoFlux := SCWRGeo2D ;
*-----------------------------------------
*Definir et analyser les geometries de calculs
*-----------------------------------------
VolumAutoPro LignAutoPro VolumFlux LignFlux := SCWRTrack2D
  GeoAutoPro GeoFlux ;

*PSGEOAuto.ps := PSP: VolumAutoPro ::
```

```
*FILL RGB TYPE MIXTURE EDIT 0
* ;

*PSGEOFlux.ps := PSP: VolumFlux ::
*FILL RGB TYPE MIXTURE EDIT 0
* ;

*END: ;

*----------------------------------------------
EVALUATE TFuel     := 1154.4 ;
EVALUATE TCalo     := 876.8545 ;
EVALUATE DCalo     := 0.1746768 ;
EVALUATE DCaloIsol := 0.0977856 ;

*-----------------------------
*Creer la bibliotheque interne
*-----------------------------
BiblioInt := SCWRLib1 :: <<TCalo>> <<DCalo>> <<DCaloIsol>> <<TFuel>> ;
*----------------------------------------
*Calculer le flux dans la cellule unitaire
*----------------------------------------
DBRef Resultats ConcIso BiblioInt := EvolRefB BiblioInt VolumAutoPro
VolumFlux LignAutoPro LignFlux  :: <<Bundle_Power>> ;

*Resultats := SCWRFlux BiblioInt VolumAutoPro LignAutoPro
*  VolumFlux LignFlux ;
*-------------------------
*Recuperation des resultats
*-------------------------
Res.res := Resultats ;
*---------
*Nettoyage
*---------
*Resultats ConcIso := DELETE: Resultats ConcIso ;
BiblioInt := DELETE: BiblioInt ;
```

```
GeoAutoPro GeoFlux := DELETE: GeoAutoPro GeoFlux ;
VolumAutoPro VolumFlux := DELETE: VolumAutoPro VolumFlux ;
LignAutoPro LignFlux := DELETE: LignAutoPro LignFlux ;
END: ;
QUIT "LIST" .
```

B.2 Procedures

B.2.1 Procedure SCWRLib1

```
*DECK SCWRLib
*------------
*Nom             : SCWRLib.c2m
*Usage           : Definir les melanges de la cellule unitaitre du SCWR
*Auteur          : G. Harrisson
*Date            : 2010/11/04
*Modifier        : Mai 2011 par P. Adouki
*
*Description de la procedure:
*BiblioInt := SCWRLib :: <<TCalo>> <<DCalo>> <<DCaloIsol>> ;
*TCalo     : Temperature du caloporteur en K
*DCalo     : Densite du caloporteur en g/cm3
*DCaloIsol : Densite du caloporteur a la temperature de l'isolant en g/cm3
*BiblioInt : Bibliotheque interne requise pour les calculs
*
*----------------------------------------------------------------------
*Definir les structures de donnees des parametres et les modules utilises
*----------------------------------------------------------------------
PARAMETER  BiblioInt :: ::: XSM_FILE BiblioInt ; ;
MODULE  INFO: LIB: DELETE: END: ;
*----------------------------------------
*Lire les variables transmises a la procedure
*----------------------------------------
REAL  TCalo     DCalo     DCaloIsol   TFuel ;
::  >>TCalo<< >>DCalo<< >>DCaloIsol<< >>TFuel<< ;
*---------------------------
*Definir les variables locales
```

```
*----------------------------
REAL TLiner     TTubFrc    TGaine      TIsol
     WgtH1Calo  WgtD2Calo  WgtO16Calo  PureteCalo
     WgtH1Mod   WgtD2Mod   WgtO16Mod   PureteMod ;
*-----------------------------------------------------
*Definir la temperature des melanges a partir de TCalo
*-----------------------------------------------------
EVALUATE TLiner  := TCalo ;
EVALUATE TTubFrc := 0.3324 TCalo * 267.36 + ;
EVALUATE TGaine  := 0.4989 TCalo * 480.87 + ;
EVALUATE TIsol   := 0.666  TCalo * 133.73 + ;
*-----------------------------------------------------------
*Definir la purete de l'eau du caloporteur et du moderateur
*-----------------------------------------------------------
EVALUATE PureteCalo := 0.0156 ;
EVALUATE PureteMod  := 99.833 ;
*-------------------------------------------------------------------------------
*Composition isotopique (en % massique) de l'eau du calcoporteur et du moderateur
*-------------------------------------------------------------------------------
INFO: ::
  PUR: <<PureteCalo>>   ATM%
  LIB: WIMSD4 FIL: endfb7
  ISO: 3 '3001'   '3002'   '6016'
  CALC WGT% D2O >>WgtH1Calo<< >>WgtD2Calo<< >>WgtO16Calo<< ;
INFO: ::
  PUR: <<PureteMod>>   ATM%
  LIB: WIMSD4 FIL: endfb7
  ISO: 3 '3001'   '3002'   '6016'
  CALC WGT% D2O >>WgtH1Mod<< >>WgtD2Mod<< >>WgtO16Mod<< ;
*-------------------------
*Donnees IAEA - ENDF/B-VII
*-------------------------
BiblioInt := LIB: ::
  EDIT 0
  NMIX 29 CTRA WIMS
  DEPL LIB: WIMSD4 FIL: endfb7
```

```
  MIXS LIB: WIMSD4 FIL: endfb7
*---------------------------------
*Definir les melanges de la cellule
*---------------------------------
*CALOPORTEUR (Eau legere : 99.984 %ATM H2O & 0.0156 %ATM D2O)
*-------------------------------------------------------------
  MIX  1  <<TCalo>>   <<DCalo>>
    H1  = '3001'  <<WgtH1Calo>>
    D2  = '3002'  <<WgtD2Calo>>
    O16 = '6016'  <<WgtO16Calo>>

*LINER (30 % Acier inoxydable 310 et 70 % Caloporteur)
*-----------------------------------------------------
  MIX  2  <<TLiner>>  7.75
    C    = '2012'   0.250
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433

  MIX 3 COMB 2 0.30 1 0.70

*ISOLANT (30 % ZrO2 et 70 % Caloporteur)
*---------------------------------------
  MIX 4  <<TIsol>>  5.68
    Zr   = '91'    100.0026
    O16  = '6016'   35.0684

  MIX 5  <<TIsol>>  <<DCaloIsol>>
    H1  = '3001'  <<WgtH1Calo>>
    D2  = '3002'  <<WgtD2Calo>>
    O16 = '6016'  <<WgtO16Calo>>
```

```
  MIX 6 COMB 4 0.30 5 0.70

*TUBE DE FORCE (Alliage de Zr : Zr-2.5Nb)
*----------------------------------------
  MIX 7  <<TTubFrc>>  6.515
    Nb93 = '93'  2.58
    Fe   = '2056'   0.046780177764
    Cr   = '52'     0.008087975736
    Ni   = '58'     0.0035
    B10  = '1010'   0.00002431
    Zr   = '91'    97.3132811882

*MODERATEUR (Eau lourde : 99.833 %ATM D2O & 0.167 %ATM H2O)
*----------------------------------------------------------
  MIX  8  342.16  1.08509
    H1  = '3001'  <<WgtH1Mod>>
    D2  = '3002'  <<WgtD2Mod>>
    O16 = '6016'  <<WgtO16Mod>>
    MB10 = '1011' 1.0E-10

*GAINE (Acier inoxydable 310)
*----------------------------
  MIX 9    <<TGaine>>  7.75
    C    = '2012'   0.250
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433

*COMBUSTIBLE 1 (90% Thorium et 10% Plutonium recycle)
*---------------------------------------------------
  MIX  10  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
```

```
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
    Pu238 = '948'    2.5     1
    Pu239 = '6239'  54.2     1
    Pu240 = '1240'  23.8     1
    Pu241 = '1241'  12.6     1
    Pu242 = '242'    6.8     1

  MIX 11  <<TFuel>>  9.70
    Th232 = '2232'  100.0    1
    Pa233 = '1233'    0.0    1
    U233  = '9233'    0.0    1
    O16   = '6016'   13.79

  MIX 12 COMB 10 0.12 11 0.88

*COMBUSTIBLE 2 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
  MIX  13  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
    Pu238 = '948'    2.5     2
    Pu239 = '6239'  54.2     2
    Pu240 = '1240'  23.8     2
    Pu241 = '1241'  12.6     2
    Pu242 = '242'    6.8     2

  MIX 14  <<TFuel>>  9.70
    Th232 = '2232'  100.0    2
    Pa233 = '1233'    0.0    2
    U233  = '9233'    0.0    2
    O16   = '6016'   13.79
```

```
  MIX 15 COMB 13 0.12 14 0.88

*COMBUSTIBLE 3 (90% Thorium et 10% Plutonium recycle)
*----------------------------------------------------
  MIX  16  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
    Pu238 = '948'    2.5     3
    Pu239 = '6239'  54.2     3
    Pu240 = '1240'  23.8     3
    Pu241 = '1241'  12.6     3
    Pu242 = '242'    6.8     3

  MIX 17  <<TFuel>>  9.70
    Th232 = '2232'  100.0    3
    Pa233 = '1233'    0.0    3
    U233  = '9233'    0.0    3
    O16   = '6016'   13.79

  MIX 18 COMB 16 0.12 17 0.88

*COMBUSTIBLE 4 (90% Thorium et 10% Plutonium recycle)
*----------------------------------------------------
  MIX  19  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
    Pu238 = '948'    2.5     4
    Pu239 = '6239'  54.2     4
    Pu240 = '1240'  23.8     4
    Pu241 = '1241'  12.6     4
    Pu242 = '242'    6.8     4
```

```
  MIX 20  <<TFuel>>  9.70
    Th232 = '2232'  100.0    4
    Pa233 = '1233'    0.0    4
    U233  = '9233'    0.0    4
    O16   = '6016'   13.79

  MIX 21 COMB 19 0.12 20 0.88

*COMBUSTIBLE 5 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
  MIX  22  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
    Pu238 = '948'    2.5     5
    Pu239 = '6239'  54.2     5
    Pu240 = '1240'  23.8     5
    Pu241 = '1241'  12.6     5
    Pu242 = '242'    6.8     5

  MIX 23  <<TFuel>>  9.70
    Th232 = '2232'  100.0    5
    Pa233 = '1233'    0.0    5
    U233  = '9233'    0.0    5
    O16   = '6016'   13.79

  MIX 24 COMB 22 0.12 23 0.88

*COMBUSTIBLE 6 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
  MIX  25  <<TFuel>>  9.70
    Xe135 = '4135'   1.0E-24
    Sm149 = '4149'   1.0E-24
    Np239 = '1939'   1.0E-24
    O16   = '6016'  13.389
```

```
    Pu238 = '948'    2.5     6
    Pu239 = '6239'  54.2     6
    Pu240 = '1240'  23.8     6
    Pu241 = '1241'  12.6     6
    Pu242 = '242'    6.8     6

  MIX 26  <<TFuel>>  9.70
    Th232 = '2232'  100.0    6
    Pa233 = '1233'    0.0    6
    U233  = '9233'    0.0    6
    O16   = '6016'   13.79

  MIX 27 COMB 25 0.12 26 0.88

*PIN CENTRALE (Eau legere : 99.984 %ATM H2O & 0.0156 %ATM D2O)
*-------------------------------------------------------------
  MIX  28  <<TCalo>>   <<DCalo>>
    H1  = '3001'  <<WgtH1Calo>>
    D2  = '3002'  <<WgtD2Calo>>
    O16 = '6016'  <<WgtO16Calo>>

*GAINE PIN CENTRALE (Acier inoxydable 310)
*----------------------------------------
  MIX 29    <<TGaine>>  7.75
    C    = '2012'   0.250
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433 ;

END: ;
QUIT "LIST" .
```

B.2.2 Procedure SCWRGeo2D

```
*DECK SCWRGeo2D
*--------------
*  Nom           : SCWRGeo2D.c2m
*  Usage         : Definir les geometries 2D du SCWR pour le calcul de l'autoprotection
*                  Geometrie a 54 crayons de combustible
*  Auteur        : G. Harrisson
*  Date          : 2010/11/18
*  Modifier      : 2011/02/07
*
*Description de la procedure:
*GeoAutoPro GeoFlux := SCWRGeo ;
*GeoAutoPro : Geometrie pour le calcul de l'autoprotection des resonances
*GeoFlux    : Geometrie pour le calcul du flux
*----------------------------------------------------------------------
*Definir les structures de donnees des parametres et les modules utilises
*----------------------------------------------------------------------
PARAMETER  GeoAutoPro GeoFlux :: ::: LINKED_LIST GeoAutoPro GeoFlux ; ;
MODULE     GEO: END: ;
*----------------------------------------------------------
*Geometrie pour le calcul de l'autoprotection des resonances
*----------------------------------------------------------
GeoAutoPro := GEO: :: CARCEL 8 3 3
   EDIT 0
   X- REFL MESHX -12.5 -8.4853 8.4853 12.5 X+ REFL
   Y- REFL MESHY -12.5 -8.4853 8.4853 12.5 Y+ REFL
   RADIUS  0.00000  2.10480  3.60300  5.06525  6.80000  6.90000
           8.23000  9.63000  12.00000
   MIX     1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
```

```
            1 1 1 1 3 6 7 8 8
   CLUSTER ROD1 ROD2 ROD3 ROD4
      ::: ROD1 := GEO: TUBE 2
           RADIUS 0.000 1.800 2.000
           MIX  28 29
           NPIN  1 RPIN 0.0000 APIN 0.0000 ;
      ::: ROD2 := GEO: TUBE 2 1 2
           RADIUS 0.000 0.620 0.660
           MESHX -0.660       0.660
           MESHY -0.660 0.000 0.660
           MIX 12 9 15 9
           NPIN  12 RPIN 2.8755  APIN 0.2618 ;
      ::: ROD3 := GEO: TUBE 2 1 2
           RADIUS 0.000 0.620 0.660
           MESHX -0.660       0.660
           MESHY -0.660 0.000 0.660
           MIX 18 9 21 9
           NPIN 18 RPIN 4.3305  APIN 0.1745 ;
      ::: ROD4 := GEO: TUBE 2 1 2
            RADIUS 0.000 0.620 0.660
            MESHX -0.660       0.660
            MESHY -0.660 0.000 0.660
            MIX 24 9 27 9
            NPIN 24 RPIN 5.8000  APIN 0.1309 ; ;
*--------------------------------
*Geometrie pour le calcul du flux
*--------------------------------
GeoFlux := GEO: GeoAutoPro :: SPLITR 1 21 21 21 1 14 3 7
                              SPLITX 4 1 4
                              SPLITY 4 1 4
   ::: ROD1 := GEO: ROD1 SPLITR 1 1 ;
   ::: ROD2 := GEO: ROD2 SPLITR 4 1 ;
   ::: ROD3 := GEO: ROD3 SPLITR 4 1 ;
   ::: ROD4 := GEO: ROD4 SPLITR 4 1 ; ;
END: ;
QUIT "LIST" .
```

B.2.3 Procedure SCWRTrack2D

```
*DECK SCWRTrack2D
*----------------
*  Nom           : SCWRTrack2D.c2m
*  Utilisation   : Definir et analyser les geometries de calculs
*  Auteur        : G. Harrisson
*  Date          : 2011/02/07
*
*Description de la procedure:
*VolumAutoPro LignAutoPro VolumFlux LignFlux := SCWRTrack2D GeoAutoPro GeoFlux ;
*VolumAutoPro : Fichier de tracking de la geometrie de calcul pour l'autoprotection des
*LignAutoPro  : Fichier de lignes d'integration de la geometrie de calcul pour l'autopro
*VolumFlux    : Fichier de tracking de la geometrie de calcul pour le flux
*LignFlux     : Fichier de lignes d'integration de la geometrie de calcul pour le flux
*GeoAutoPro   : Geometrie de base pour le calcul de l'autoprotection des resonances
*GeoFlux      : Geometrie de base pour le calcul du flux
*
*----------------------------------------------------------------------
*Definir les structures de donnees des parametres et les modules utilises
*----------------------------------------------------------------------
PARAMETER  VolumAutoPro LignAutoPro VolumFlux LignFlux
           GeoAutoPro GeoFlux ::
            ::: LINKED_LIST VolumAutoPro VolumFlux GeoAutoPro GeoFlux ;
            ::: SEQ_BINARY LignAutoPro LignFlux ; ;
MODULE NXT: DELETE: END: ;
*----------------------------------------
*Analyser et tracker les geometries de base
*----------------------------------------
VolumAutoPro LignAutoPro := NXT: GeoAutoPro :: EDIT 10 TISO 20 20.0 ;
VolumFlux    LignFlux    := NXT: GeoFlux    :: EDIT 10 TISO 20 35.0 ;

END: ;
QUIT "LIST" .
```

B.2.4 EvolRefB

```
*DECK EvolRefB
*----------
*  Nom           : EvolRefB.c2m
*  Usage         : Resoudre pour les flux, evoluer et generer le fichier de resultats de
*  Auteur        : G. Harrisson
*  Date          : 2009/11/24
*
*  Description de la procedure:
*
*  EditDS ConcIso := EvolRefB MicLib TrackingS TrackingF IntlineS IntlineF ::
*                    <<Puissance>> >>NbEtapes<< ;
*
*  MicLib        : Microlib requise pour calcul
*  Puissance     : Puissance specifique de grappe en kW/kg
*  NbEtapes      : Nombre d'etapes d'evolution
*  EditDS        : Fichier de resultats
*  ConcIso       : Concentration isotopiques en fonction du temps
*
*----------
* Definir les structures de donnees des parametres
*----------
PARAMETER  DBRef EditDS ConcIso MicLib TrackingS TrackingF
           IntlineS IntlineF ::
  ::: SEQ_ASCII DBRef                              ;
  ::: XSM_FILE    EditDS     ConcIso  MicLib       ;
  ::: LINKED_LIST TrackingS TrackingF              ;
  ::: SEQ_BINARY  IntlineS IntlineF                ; ;
*----------
*  Recuperer l'information transferee a la procedure
*----------
REAL     Puissance ;
INTEGER  NbEtapes  ;
::  >>Puissance<< ;
ECHO "Puissance specifique de grappe =" Puissance "kW/kg"  ;
*----------
```

```
*  Modules et structures de donnees et variables
*----------
MODULE       SHI: ASM: FLU: EDI: EVO:
             GREP:  DELETE: CPO:             ;
LINKED_LIST  TmpMicLib CPODB ;
XSM_FILE     PIJ Flux  ;
REAL         keff              ;
INTEGER      FinEvo   := 0     ;
REAL         klower   := 0.98  ;
REAL         iBurn    := 0.    ;
REAL         DBURN    := 12.5  ;
REAL         Delt     := DBURN Puissance / ;
*----------
*  1er Calcul de flux complet
*  1) Auto-protection
*  2) Assemblage
*  3) Calcul de flux
*  4) Edition
*----------
TmpMicLib := MicLib ;
EVALUATE NbEtapes := 1 ;
TmpMicLib := SHI: TmpMicLib TrackingS IntlineS   :: EDIT 0   ;
PIJ  := ASM: TmpMicLib TrackingF IntlineF        :: EDIT 0   ;
Flux := FLU: PIJ TmpMicLib TrackingF             :: TYPE K   ;
EditDS := EDI: Flux TmpMicLib TrackingF          :: EDIT 4
          COND 0.625 MERG COMP SAVE ;
PIJ := DELETE:  PIJ ;
*----------
*  Boucle d'evolution
*----------
WHILE FinEvo 1 < DO
  IF iBurn 0. = THEN
    ConcIso TmpMicLib := EVO:         TmpMicLib Flux TrackingF ::
      DEPL <<Delt>>  DAY POWR <<Puissance>> ;
  ELSE
    ConcIso TmpMicLib := EVO: ConcIso TmpMicLib Flux TrackingF ::
```

```
      DEPL <<Delt>>  DAY POWR <<Puissance>> ;
  ENDIF ;
  EVALUATE  iBurn    := iBurn DBURN + ;
*----------
*  Calcul de flux complet pour differentes etapes d'evolution
*  1) Auto-protection
*  2) Assemblage
*  3) Calcul de flux
*  4) Edition
*----------
TmpMicLib := SHI: TmpMicLib TrackingS IntlineS     :: EDIT 0   ;
PIJ    := ASM: TmpMicLib TrackingF IntlineF        :: EDIT 0   ;
Flux   := FLU: Flux PIJ TmpMicLib TrackingF        :: TYPE K   ;
EditDS := EDI: EditDS Flux TmpMicLib TrackingF     :: EDIT 4
            COND 0.625 MERG COMP SAVE ;
PIJ := DELETE:  PIJ ;
*----------
*  Changer Delta t lorsque requis
*----------
  IF iBurn       150. = THEN
    EVALUATE  DBURN := 25.    ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn   250. = THEN
    EVALUATE  DBURN := 50.    ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn   500. = THEN
    EVALUATE  DBURN := 100.   ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn  1000. = THEN
    EVALUATE  DBURN := 200.   ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn  2000. = THEN
    EVALUATE  DBURN := 500.   ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn  4000. = THEN
    EVALUATE  DBURN := 1000.  ;
```

```
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn  6000. = THEN
    EVALUATE  DBURN := 2000.  ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn 10000. = THEN
    EVALUATE  DBURN := 5000.  ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn 30000. = THEN
    EVALUATE  DBURN := 10000. ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn 40000. = THEN
    EVALUATE  DBURN := 20000. ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn 60000. = THEN
    EVALUATE  DBURN := 20000. ;
    EVALUATE  Delt  := DBURN Puissance / ;
  ELSEIF iBurn 80000. = THEN
    EVALUATE  DBURN := 20000. ;
    EVALUATE  Delt  := DBURN Puissance / ;

 ENDIF ;
*----------
*  Verifier si keff < klower
*----------
*  GREP: Flux :: GETVAL 'K-EFFECTIVE' 1 >>keff<< ;
*  ECHO "k-eff ="  keff ;
!  IF keff klower < THEN
!    EVALUATE FinEvo := 1 ;
!  ENDIF ;
  IF iBurn 0. > THEN
    EVALUATE FinEvo := 1 ;
  ENDIF ;
ENDWHILE ;

CPODB := CPO: ConcIso EditDS ::
 BURNUP REF-CASE
```

```
* EXTRACT Xe135  Xe135
* EXTRACT Sm149  Sm149
* EXTRACT Np239  Np239
 NAME MELANGE ;
DBRef := CPODB ;

*----------
*  Nettoyer
*----------
Flux TmpMicLib := DELETE: Flux TmpMicLib ;
*----------
*  Retourner nombre de calculs
*----------

QUIT .
```

APPENDIX C

DRAGON input files for database generation

C.1 Main input files

C.1.1 File RefG2.x2m

```
*DECK RefG2.x2m
*----
*  Nom           : RefG2.x2m
*  Type          : DRAGON input file
*  Usage         : Reference G2 calculations
*  Auteur        : G. Marleau
*                  P. Adouki (Summer 2011)
*
*----
* Modules ond procedures
*----
MODULE    DELETE: END: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Ref CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib EditPu ;
SEQ_ASCII   EditRef.exp ConcIso.exp MicLib.exp
            CPMREF.exp MLDREF.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option ;

REAL      TComb   TCalo    TMode        DCalo
```

```
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;
INTEGER   NbEtapes := 3 ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Cross section library
*----
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
*----
*  Reference burnup calculation
*----
EditDS ConcIso := EvoG2Ref  MicLib TrackS TrackF
                                   LinesS LinesF ::
  <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
EditRef.exp := EditDS ;
ConcIso.exp := ConcIso ;
MicLib.exp  := MicLib ;
STRING NomDB NomEdit := "REF" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
```

```
  <<NomDB>> <<NomEdit>> ;
CPMREF.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EVALUATE NomDB NomEdit := "MODREF" "Reflect" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
MLDREF.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS ConcIso MicLib := DELETE: EditDS ConcIso MicLib ;
TrackS TrackF LinesS LinesF := DELETE:
  TrackS TrackF LinesS LinesF ;
END: ;
QUIT "LIST" .
```

C.1.2 File CFC.x2m

```
*----------------------CFC.x2m---------------------------
*----
*  DRAGON CPO files for reference and
*  perturbed calculation
*----
SEQ_ASCII    CPMREF.exp  CPMBM.exp   CPMXE5.exp  CPMTF1.exp
             CPMTF2.exp  CPMTC1.exp  CPMTC2.exp  CPMTM1.exp
             CPMTM2.exp  CPMDC1.exp  CPMDC2.exp  CPMDM1.exp
             CPMDM2.exp  CPMSM9.exp  CPMNP9.exp  CPMCP1.exp
             CPMCP2.exp  CPMPM.exp   CPMHPI.exp  CPMHPD.exp
             CPMHPU.exp  MLDREF.exp  MLDBM.exp   MLDTM1.exp
             MLDTM2.exp  MLDDM1.exp  MLDDM2.exp  MLDPM.exp   ;


*----
*  Output FBM data base
*----
SEQ_ASCII    FBMDAT  ;
*----
*  Local data structure
*----
```

```
XSM_FILE     CPMREFXSM  CPMBORXSM  CPMXENXSM  CPMT1FXSM  CPMT2FXSM
             CPMT1CXSM  CPMT2CXSM  CPMT1MXSM  CPMT2MXSM  CPMD1CXSM
             CPMD2CXSM  CPMD1MXSM  CPMD2MXSM  CPMSM1XSM  CPMNP9XSM
             CPMMFDXSM  CPMMMDXSM  CPMPURXSM  CPMHP3XSM  CPMHPDXSM
             CPMHPUXSM  MLDREFXSM  MLDBORXSM  MLDT1MXSM  MLDT2MXSM
             MLDD1MXSM  MLDD2MXSM  MLDPURXSM  EDIDAT ;
*----
*  Dragon modules used
*----
MODULE       CFC: END: DELETE: ;
*----
*  Import CPO ASCII files XSM format for DRAGON processing
*----
CPMREFXSM  := CPMREF.exp ;
CPMBORXSM  := CPMBM.exp  ;
CPMXENXSM  := CPMXE5.exp ;
CPMT1FXSM  := CPMTF1.exp ;
CPMT2FXSM  := CPMTF2.exp ;
CPMT1CXSM  := CPMTC1.exp ;
CPMT2CXSM  := CPMTC2.exp ;
CPMT1MXSM  := CPMTM1.exp ;
CPMT2MXSM  := CPMTM2.exp ;
CPMD1CXSM  := CPMDC1.exp ;
CPMD2CXSM  := CPMDC2.exp ;
CPMD1MXSM  := CPMDM1.exp ;
CPMD2MXSM  := CPMDM2.exp ;
CPMSM1XSM  := CPMSM9.exp ;
CPMNP9XSM  := CPMNP9.exp ;
CPMMFDXSM  := CPMCP1.exp ;
CPMMMDXSM  := CPMCP2.exp ;
CPMPURXSM  := CPMPM.exp  ;
CPMHP3XSM  := CPMHPI.exp ;
CPMHPDXSM  := CPMHPD.exp ;
CPMHPUXSM  := CPMHPU.exp ;
MLDREFXSM  := MLDREF.exp ;
MLDBORXSM  := MLDBM.exp  ;
```

```
MLDT1MXSM  := MLDTM1.exp ;
MLDT2MXSM  := MLDTM2.exp ;
MLDD1MXSM  := MLDDM1.exp ;
MLDD2MXSM  := MLDDM2.exp ;
MLDPURXSM  := MLDPM.exp  ;
*----
*  Generate FBM database
*----
EDIDAT := CFC: CPMREFXSM CPMT1FXSM CPMT2FXSM CPMT1CXSM
               CPMT2CXSM CPMT1MXSM CPMT2MXSM CPMD1CXSM
               CPMD2CXSM CPMD1MXSM CPMD2MXSM CPMBORXSM
               CPMPURXSM CPMXENXSM CPMSM1XSM CPMNP9XSM
               CPMMFDXSM CPMMMDXSM CPMHPUXSM CPMHP3XSM
               CPMHPDXSM MLDREFXSM MLDT1MXSM MLDT2MXSM
               MLDD1MXSM MLDD2MXSM MLDBORXSM MLDPURXSM ::
  INFOR SCWR_DATABASE DNAME FBMDATA
  PWR 755.95 2000.0 500.0 30.0
  TCOOL 923.15 1473.15 573.15
  TMODE 342.16 372.16 292.16
  TFUEL 1273.15 1773.15 773.15
  XIR 1.0E-24 2.0E-9
  RHOM 1.08509
  RHOC 0.35

;
*----
*  Export FBM database in ASCII format
*----
FBMDAT :=  EDIDAT ;
*----
*  Clean up
*----
CPMREFXSM  CPMBORXSM  CPMXENXSM  CPMT1FXSM  CPMT2FXSM
CPMT1CXSM  CPMT2CXSM  CPMT1MXSM  CPMT2MXSM  CPMD1CXSM
CPMD2CXSM  CPMD1MXSM  CPMD2MXSM  CPMSM1XSM  CPMNP9XSM
CPMMFDXSM  CPMMMDXSM  CPMPURXSM  CPMHP3XSM  CPMHPDXSM
```

```
CPMHPUXSM  MLDREFXSM  MLDBORXSM  MLDT1MXSM  MLDT2MXSM
MLDD1MXSM  MLDD2MXSM  MLDPURXSM  EDIDAT := DELETE:
CPMREFXSM  CPMBORXSM  CPMXENXSM  CPMT1FXSM  CPMT2FXSM
CPMT1CXSM  CPMT2CXSM  CPMT1MXSM  CPMT2MXSM  CPMD1CXSM
CPMD2CXSM  CPMD1MXSM  CPMD2MXSM  CPMSM1XSM  CPMNP9XSM
CPMMFDXSM  CPMMMDXSM  CPMPURXSM  CPMHP3XSM  CPMHPDXSM
CPMHPUXSM  MLDREFXSM  MLDBORXSM  MLDT1MXSM  MLDT2MXSM
MLDD1MXSM  MLDD2MXSM  MLDPURXSM  EDIDAT ;
END: ;
QUIT "LIST" .
```

C.1.3 File PerG2BM.x2m

```
 *DECK PerG2BM.x2m
*----
*  Nom           : PerG2BM.x2m
*  Type          : DRAGON input file
*  Usage         : G2 perturbative calculations
*                  for moderator boron BM
*  Auteur        : G. Marleau
*                  P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditBM.exp
            CPMBM.exp
            MLDBM.exp ;
EditRef  := EditRef.exp ;
```

```
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option   ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.  -1.   -1. ;
STRING    NomDB NomEdit  ;
*----
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Reference library parameters
*----
```

```
REAL  Ctemp  Mtemp Ftemp :=  923.15 345.66 1273.15 ;
*----
*  Perturb moderator boron
*----
EVALUATE Bore  := 0.0  ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditBM.exp := EditDS ;
EVALUATE  NomDB NomEdit    := "BORON" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMBM.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EVALUATE    NomDB NomEdit    := "MODBOR" "Reflect" ;
CpoDS := CpoG2 EditDS ConcIso ::
   <<NomDB>> <<NomEdit>> ;
MLDBM.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS MicLib := DELETE: EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.4 File PerG2CMB.x2m

```
 *DECK PerG2CMB.x2m
*----
*  Nom           : PerG2CMB.x2m
*  Type          : DRAGON input file
*  Usage         : G2 cpmbined perturbative calculations
```

```
*                  for TF/DC and TC/DC
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditCP1.exp EditCP2.exp
            CPMCP1.exp CPMCP2.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING     Option ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
STRING    NomDB NomEdit  ;
```

```
*----
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp := 923.15 345.66 1273.15 ;
*----
*  Perturb TF/DC
*----
EVALUATE TComb TCalo := Ftemp 500.0 + Ctemp ;
EVALUATE DCalo  := 0.0001  ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditCP1.exp := EditDS ;
```

```
EVALUATE    NomDB NomEdit    := "MIXFD" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMCP1.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
*----
*  Perturb TC/DC
*----
EVALUATE TComb TCalo := Ftemp Ctemp 550.0 + ;
EVALUATE DCalo  := 0.0001  ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditCP2.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "MIXMD" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMCP2.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.5 File PerG2DM.x2m

```
 *DECK PerG2DC.x2m
*----
*  Nom           : PerG2DM.x2m
*  Type          : DRAGON input file
```

```
*  Usage          : G2 perturbative calculations
*                   for coolant density DC
*  Auteur         : G. Marleau
*      P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditDC1.exp EditDC2.exp
            CPMDC1.exp CPMDC2.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING     Option  ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
```

```
STRING    NomDB NomEdit  ;
*----
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;

*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;

*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp :=  923.15 345.66 1273.15 ;
*----
*  Perturb moderator density to 0.0001
*----
*EVALUATE DCalo  :=   0.03 ;
EVALUATE DCalo  :=   0.0001 ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
```

```
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditDC1.exp := EditDS ;
EVALUATE  NomDB NomEdit    := "CDEN-D" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMDC2.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS MicLib := DELETE: EditDS MicLib ;
*----
*  Perturb moderator density to 0.7
*----
EVALUATE DCalo  := 0.7  ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditDC2.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "CDEN-UP" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMDC1.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS MicLib := DELETE: EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.6 File PerG2IF.x2m

```
 *DECK PerG2IF.x2m
*----
*  Nom           : PerG2IF.x2m
*  Type          : DRAGON input file
*  Usage         : G2 perturbative calculations
*                  for fuel isotopes perturbations
*                  (Xe-135, Sm-149 and Np-239).
*  Auteur        : G. Marleau
*          P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp temp ;
SEQ_ASCII   EditXE5.exp EditSM9.exp EditNP9.exp
            CPMXE5.exp CPMSM9.exp CPMNP9.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
```

```
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
STRING    NomDB NomEdit  ;
*----
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp := 923.15 345.66 1273.15 ;
*----
*  Perturb Xenon 135
*----
EVALUATE  ChangXe ChangSm ChangNp := 2.0E-9 -1.0 -1.0 ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
```

```
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditXE5.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "XENON" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMXE5.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
*----
*  Perturb Sm-149
*----
EVALUATE  ChangXe ChangSm ChangNp := -1.0 7.0E-8 -1.0 ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditSM9.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "SM149 " "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMSM9.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
*----
*  Perturb Np-239
*----
EVALUATE  ChangXe ChangSm ChangNp := -1.0 -1.0  3.0E-12 ;
```

```
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditNP9.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "NP239" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMNP9.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.7 File PerG2PM.x2m

```
 *DECK PerG2PM.x2m
*----
*  Nom           : PerG2PM.x2m
*  Type          : DRAGON input file
*  Usage         : G2 perturbative calculations
*                  for moderator purity PM
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
```

```
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditPM.exp
            CPMPM.exp
            MLDPM.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
STRING    NomDB NomEdit  ;
*----
* Get number of burnup steps from ConcIso
*----
```

```
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;

TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp := 923.15 345.66 1273.15 ;
*----
*  Perturb moderator boron
*----
EVALUATE PMode  := 98.5 ;

MicLib := DELETE: MicLib ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditPM.exp := EditDS ;
EVALUATE  NomDB NomEdit    := "PURITY" "Nominal" ;
```

```
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMPM.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EVALUATE    NomDB NomEdit    := "MODPUR" "Reflect" ;
CpoDS := CpoG2 EditDS ConcIso ::
   <<NomDB>> <<NomEdit>> ;
MLDPM.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS MicLib := DELETE: EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.8 File PerPowG2.x2m

```
 *DECK PerPowG2.x2m
*----
*  Nom           : PerPowG2.x2m
*  Type          : DRAGON input file
*  Usage         : Power perturbations for G2 calculations
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    DELETE: END: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Ref CpoG2 EvoG2Pui ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib EditPu ;
SEQ_ASCII   EditPw1.exp EditPw2.exp EditPw3.exp
            CIPw1.exp CIPw2.exp CIPw3.exp
            CPMHPD.exp CPMHPU.exp CPMHPI.exp ;
```

```
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes := 3 ;
REAL      RefPower MaxBurn := 24.13 25000.0 ;
REAL Puissance ;
*----
*  Self shielding geometry
*----

EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 :: <<Option>> ;

*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;

EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;

*----
*  Perturbed burnup calculation
*----
EVALUATE Puissance := 0.9576 ;
```

```
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS ConcIso := EvoG2Pui  MicLib TrackS TrackF
                                   LinesS LinesF ::
  <<RefPower>> <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
EditPw1.exp := EditDS ;
CIPw1.exp   := ConcIso ;
STRING NomDB NomEdit := "POWER-D" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMHPD.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS ConcIso MicLib := DELETE: EditDS ConcIso MicLib ;
*----
*  Perturbed burnup calculation
*----
EVALUATE Puissance := 63.84 ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS ConcIso := EvoG2Pui  MicLib TrackS TrackF
                                   LinesS LinesF ::
  <<RefPower>> <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
EditPw2.exp := EditDS ;
CIPw2.exp   := ConcIso ;
EVALUATE NomDB NomEdit := "POWER-UP" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
```

```
CPMHPU.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS ConcIso MicLib := DELETE: EditDS ConcIso MicLib ;
*----
*  Perturbed burnup calculation
*----
EVALUATE Puissance := 15.96 ;

MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;

EditDS ConcIso := EvoG2Pui  MicLib TrackS TrackF
                                   LinesS LinesF ::
  <<RefPower>> <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
EditPw3.exp := EditDS ;
CIPw3.exp   := ConcIso ;
EVALUATE NomDB NomEdit := "POWER-IN" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMHPI.exp := CpoDS ;
CpoDS := DELETE: CpoDS ;
EditDS ConcIso MicLib := DELETE: EditDS ConcIso MicLib ;
TrackS TrackF LinesS LinesF := DELETE:
  TrackS TrackF LinesS LinesF ;
END: ;
QUIT "LIST" .
```

C.1.9 File PerG2TC.x2m

```
 *DECK PerG2TC.x2m
*----
*  Nom           : PerG2TC.x2m
*  Type          : DRAGON input file
*  Usage         : G2 perturbative calculations
```

```
*                  for coolant temperature TC
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*----
* Modules ond procedures
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditTC1.exp EditTC2.exp
            CPMTC1.exp CPMTC2.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option   ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;
INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
STRING    NomDB NomEdit  ;
*----
```

```
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 ::
  <<Option>> ;
*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;
TrackF  LinesF := GeoG2 :: <<Option>> ;
*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp := 923.15 345.66 1273.15 ;
*----
*  Perturb coolant temperature by + 550.0
*----
EVALUATE TCalo  := Ctemp 550.0 + ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditTC1.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "CTEMP-UP" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
```

```
CPMTC1.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
*----
*  Perturb coolant temperature by - 350.0
*----
EVALUATE TCalo  := Ctemp 350.0 - ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditTC2.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "CTEMP-D" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMTC2.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.1.10 File PerG2TF.x2m

```
 *DECK PerG2TF.x2m
*----
*  Nom           : PerG2TF.x2m
*  Type          : DRAGON input file
*  Usage         : G2 perturbative calculations
*                  for fuel temperature TF
*  Auteur        : G. Marleau
*          P. Adouki (Summer 2011)
*----
* Modules ond procedures
```

```
*----
MODULE    GREP: RECOVER: UTL: DELETE: END: PSP: ;
PROCEDURE GeoG2 MicG2IAEA EvoG2Per CpoG2 ;
*----
* Data structures
*----
LINKED_LIST TrackS  TrackF Geometrie  EditTmp  ;
SEQ_BINARY  LinesS  LinesF   ;
XSM_FILE    CpoDS Flux EditDS ConcIso EditRef MicLib  ;
SEQ_ASCII   EditRef.exp ConcIso.exp ;
SEQ_ASCII   EditTF1.exp EditTF2.exp
            CPMTF1.exp CPMTF2.exp ;
EditRef  := EditRef.exp ;
ConcIso  := ConcIso.exp ;
*----
*  Definition of the data for the procedures
*  and initialisation of the default values
*----
STRING    Option  ;

REAL      TComb   TCalo    TMode        DCalo
          DMode   PCalo    PMode        Bore
          Xe      Sm       Np           DCaloIsol    :=
          1273.15 923.15   342.16       0.35
          1.08509 0.0156   99.833       1.0E-10
          1.0E-24 1.0E-24  1.0E-24      0.0977856 ;

INTEGER   NbEtapes ;
REAL      Puissance MaxBurn := 24.13 25000.0 ;
REAL      ChangXe ChangSm ChangNp := -1.0 -1.0 -1.0 ;
STRING    NomDB NomEdit  ;
*----
* Get number of burnup steps from ConcIso
*----
GREP: ConcIso ::
  GETVAL 'STATE-VECTOR' 3 >>NbEtapes<< ;
```

```
*----
*  Self shielding geometry
*----
EVALUATE Option  := "Shield" ;
TrackS  LinesS := GeoG2 ::
                <<Option>>   ;

*----
*  Flux calculation geometry
*---
EVALUATE  Option := "Flux" ;

TrackF  LinesF := GeoG2 ::
  <<Option>> ;
*----
*  Reference library parameters
*----
REAL  Ctemp  Mtemp Ftemp := 923.15 345.66 1273.15 ;
*----
*  Perturb fuel temperature by + 500.0
*----
EVALUATE TComb  := Ftemp 500.0 + ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditTF1.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "FTEMP-UP" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMTF1.exp := CpoDS ;
```

```
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
*----
*  Perturb fuel temperature by - 500.0
*----
EVALUATE TComb  := Ftemp 500.0 - ;
MicLib   := MicG2IAEA ::
  <<TComb>>  <<TCalo>>  <<TMode>>
  <<DCalo>>  <<DMode>>  <<PCalo>>
  <<PMode>>  <<Bore>>   <<Xe>>
  <<Sm>>     <<Np>>     <<DCaloIsol>> ;
EditDS := EvoG2Per ConcIso EditRef MicLib TrackS TrackF
                                          LinesS LinesF ::
       <<NbEtapes>>
       <<ChangXe>> <<ChangSm>> <<ChangNp>> ;
EditTF2.exp := EditDS ;
EVALUATE    NomDB NomEdit    := "FTEMP-D" "Nominal" ;
CpoDS := CpoG2 EditDS ConcIso ::
  <<NomDB>> <<NomEdit>> ;
CPMTF2.exp := CpoDS ;
CpoDS EditDS MicLib := DELETE: CpoDS EditDS MicLib ;
EditRef ConcIso := DELETE: EditRef ConcIso ;
END: ;
QUIT "LIST" .
```

C.2 Procedures

C.2.1 Procedure CpoG2.c2m

```
 *DECK CpoG2.c2m
*----
*  Nom           : CpoG2.c2m
*  Type          : DRAGON procedure
*  Usage         : Create CPO
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*  Description de la procedure:
*
```

```
*  CpoDS := CpoG2 EditDS ConcIso ::
*    <<NomDB>> <<NomEdit>> ;
*  Structures d'entree :
*    EditDS        : Reference Edition data structure.
*    ConcIso       : Burnup data structure.
*    MicLib        : Microlib
*  Parametres d'entree
*    NomDB         : Name of the CPO database.
*    NomEdit       : Name of the Edit directories.
*  Structures de sortie :
*    CpoDS         : CPO data structure
*
*----
* Definition of the data structures for the procedure.
*----
PARAMETER         CpoDS EditDS ConcIso ::
  ::: XSM_FILE    CpoDS EditDS ConcIso ;  ;
*----
*  Read input information
*----
STRING    NomDB NomEdit                  ;
::  >>NomDB<< >>NomEdit<< ;
*----
*  Define modules, data structures and variables
*----
MODULE       CPO:  DELETE: END:               ;
IF NomEdit "Nominal" = THEN
  CpoDS := CPO: EditDS ConcIso ::
    EDIT 0
    BURNUP <<NomEdit>>
    EXTRACT BMOD MB10
    EXTRACT CWAT CO16 CD2 CH1
    EXTRACT MWAT MO16 MD2 MH1
    EXTRACT XE135  Xe135
    EXTRACT SM149  Sm149
    EXTRACT NP239  Pa233 Np239
```

```
    EXTRACT FPC    U233 Pu239 Pu240 Pu241
    NAME <<NomDB>> ;
ENDIF ;
IF NomEdit "Reflect" = THEN
  CpoDS := CPO: EditDS ConcIso ::
     EDIT 0
    STEP 'Reflect    1'
    EXTRACT BMOD MB10
    EXTRACT MWAT MO16 MD2 MH1
    NAME <<NomDB>> ;
ENDIF ;
QUIT .
```

C.2.2 Procedure EvoG2Per.c2m

```
 *DECK EvoG2Per.c2m
*----
*  Nom           : EvoG2Per.c2m
*  Type          : Procedure DRAGON
*  Usage         : Perturbation calculations
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*  Description de la procedure:
*
*  EditDS := EvoG2Per ConcIso EditRef MicLib TrackingS TrackingF
*                                              IntlineS  IntlineF ::
*           <<NbEtapes>> <<Xe>> <<Sm>> <<Np>> ;
*  Input structures :
*    ConcIso       : Burnup data structure.
*    EditRef       : Reference Edition data structure.
*    MicLib        : Microlib
*    TrackingS     : tracking data structures for self-shielding.
*    TrackingF     : tracking data structures for flux calculations.
*    IntlineS      : Integration lines for self-shielding.
*    IntlineF      : Integration lines  for flux calculations.
*  Input variables :
*    NbEtapes      : Number of burnup steps.
```

```
*    ChangXe       : New Xe135 concentration
*    ChangSm       : New Sm149 concentration
*    ChangNp       : New Np239 concentration
*  Output structures :
*    EditDS        : Perturbed Edition data structure.
*
*----
* Definition of the data structures for the procedure.
*----
PARAMETER    EditDS ConcIso EditRef MicLib
             TrackingS TrackingF IntlineS IntlineF ::
  ::: XSM_FILE    EditDS     ConcIso  EditRef MicLib  ;
  ::: LINKED_LIST TrackingS  TrackingF        ;
  ::: SEQ_BINARY  IntlineS   IntlineF         ;    ;


*----
*  Read input information
*----
INTEGER  NbEtapes  ;
REAL     ChangXe ChangSm ChangNp ;
:: >>NbEtapes<< >>ChangXe<< >>ChangSm<< >>ChangNp<< ;
*----
*  Modules, structure de donnees et variables
*----
MODULE       LIB: SHI: ASM: FLU: EDI: EVO:
             UTL: BACKUP: RECOVER: DELETE: END:           ;
LINKED_LIST  TmpMicLib PIJ Flux EditTmp temp ;
*----
*  Variables for directory names in the Edition data structure
*----
STRING       RefDir ModDir  ;
*----
* Import MicLib in TmpMicLib
*----
TmpMicLib := MicLib ;
```

```
temp := MicLib ;
EditTmp   := EditRef ;
INTEGER  NumEtape := 0 ;
WHILE NbEtapes NumEtape  > DO
  EVALUATE  NumEtape := NumEtape 1 + ;
*----
*  Update microlib for this burnup step using ConcIso
*----
  IF NumEtape 10 < THEN
    EVALUATE  RefDir := "Nominal    " NumEtape I_TO_S +               ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  RefDir := "Nominal   "  NumEtape I_TO_S +               ;
  ELSE
    EVALUATE  RefDir := "Nominal  "   NumEtape I_TO_S +               ;
  ENDIF ;
  IF NumEtape 10 < THEN
    EVALUATE  ModDir := "Reflect    " NumEtape I_TO_S +               ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  ModDir := "Reflect   "  NumEtape I_TO_S +               ;
  ELSE
    EVALUATE  ModDir := "Reflect  "   NumEtape I_TO_S +               ;
  ENDIF ;
  TmpMicLib := LIB: TmpMicLib ConcIso ::
    BURN <<NumEtape>> MIX 11 MIX 14 MIX 17 MIX 20 MIX 23 MIX 26
                      MIX 10 MIX 13 MIX 16 MIX 19 MIX 22 MIX 25
                      MIX 12 MIX 15 MIX 18 MIX 21 MIX 24 MIX 27 ;
*----
*  Update microlib for Xe-135
*----
  IF ChangXe 0.0 > THEN
    TmpMicLib := LIB: TmpMicLib temp ::
      MAXS MIX 11 Xe135 <<ChangXe>> MIX 14 Xe135 <<ChangXe>>
           MIX 17 Xe135 <<ChangXe>> MIX 20 Xe135 <<ChangXe>>
           MIX 23 Xe135 <<ChangXe>> MIX 26 Xe135 <<ChangXe>>
           MIX 12 Xe135 <<ChangXe>> MIX 15 Xe135 <<ChangXe>>
           MIX 18 Xe135 <<ChangXe>> MIX 21 Xe135 <<ChangXe>>
```

```
          MIX 24 Xe135 <<ChangXe>> MIX 27 Xe135 <<ChangXe>> ;
  ENDIF ;
*----
*  Update microlib for Sm-149
*----
  IF ChangSm 0.0 > THEN
    TmpMicLib := LIB: TmpMicLib temp ::
      MAXS MIX 11 Sm149 <<ChangXe>> MIX 14 Sm149 <<ChangXe>>
           MIX 17 Sm149 <<ChangXe>> MIX 20 Sm149 <<ChangXe>>
           MIX 23 Sm149 <<ChangXe>> MIX 26 Sm149 <<ChangXe>>
           MIX 12 Xe135 <<ChangXe>> MIX 15 Xe135 <<ChangXe>>
           MIX 18 Xe135 <<ChangXe>> MIX 21 Xe135 <<ChangXe>>
           MIX 24 Xe135 <<ChangXe>> MIX 27 Xe135 <<ChangXe>> ;
  ENDIF ;
*----
*  Update microlib for Np-239
*----
  IF ChangNp 0.0 > THEN
    TmpMicLib := LIB: TmpMicLib temp ::
      MAXS MIX 10 Np239 <<ChangXe>> MIX 13 Np239 <<ChangXe>>
           MIX 16 Np239 <<ChangXe>> MIX 19 Np239 <<ChangXe>>
           MIX 22 Np239 <<ChangXe>> MIX 25 Np239 <<ChangXe>>
           MIX 12 Xe135 <<ChangXe>> MIX 15 Xe135 <<ChangXe>>
           MIX 18 Xe135 <<ChangXe>> MIX 21 Xe135 <<ChangXe>>
           MIX 24 Xe135 <<ChangXe>> MIX 27 Xe135 <<ChangXe>> ;
  ENDIF ;
*----
*  Flux calculation and editing
*  Recover DB2 from reference flux calculation
*----
  TmpMicLib := SHI: TmpMicLib TrackingS IntlineS     :: EDIT 0   ;
  PIJ    := ASM: TmpMicLib TrackingF IntlineF     :: EDIT 0   ;
  EditTmp := UTL: EditTmp ::
    STEP UP <<RefDir>> STEP UP FluxMultigrp ;
  Flux := RECOVER: EditTmp ;
  EditTmp := UTL: EditTmp ::
```

```
    STEP DOWN  STEP DOWN ;
  Flux   := FLU: Flux PIJ TmpMicLib TrackingF     ::
    TYPE B B1 PNL IDEM DB2  ;
  PIJ := DELETE:  PIJ ;
  IF NumEtape 1 = THEN
    EditDS := EDI:  Flux TmpMicLib TrackingF          ::
      COND 0.625 MERG COMP
      MICR ALL SAVE ON <<RefDir>>         ;
    EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
      COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
      MICR ALL SAVE ON <<ModDir>>         ;
  ELSE
    EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
      COND 0.625 MERG COMP
      MICR ALL SAVE ON <<RefDir>>         ;
    EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
      COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
      MICR ALL SAVE ON <<ModDir>>         ;
  ENDIF ;
  EditDS := UTL: EditDS ::
    STEP UP <<RefDir>> STEP UP FluxMultigrp ;
  EditDS := BACKUP: EditDS Flux ;
  EditDS := UTL: EditDS ::
    STEP DOWN  STEP DOWN ;
  Flux := DELETE: Flux ;
ENDWHILE ;
*----
*  Clean-up
*----
EditTmp TmpMicLib := DELETE: EditTmp TmpMicLib ;
QUIT "LIST" .
```

C.2.3 Procedure EvoG2Pui.c2m

```
 *DECK EvoG2Pui.c2m
*----
*  Nom           : EvoG2Pui.c2m
```

```
*  Type          : DRAGON procedure
*  Usage         : Solve transport equation and burn the fuel.
*                  Perturbed powers.
*  Auteur        : G. Marleau
*      P. Adouki (Summer 2011)
*  Description de la procedure:
*
*  EditDS ConcIso := EvoG2Pui MicLib TrackingS TrackingF
*                                    IntlineS  IntlineF ::
*    <<RefPower>> <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
*  Input structures :
*    MicLib        : Microlib
*    TrackingS     : tracking data structures for self-shielding.
*    TrackingF     : tracking data structures for flux calculations.
*    IntlineS      : Integration lines for self-shielding.
*    IntlineF      : Integration lines  for flux calculations.
*  Input variables :
*    RefPower      : Reference burnup power.
*    Puissance     : Burnup power.
*    MaxBurn       : Maximum burnup.
*    NbEtapes      : Number of burnup steps.
*  Output structures :
*    EditDS        : Reference Edition data structure.
*    ConcIso       : Burnup data structure.
*
*----
* Definition of the data structures for the procedure.
*----
PARAMETER    EditDS ConcIso MicLib
             TrackingS TrackingF IntlineS IntlineF ::
  ::: XSM_FILE    EditDS  ConcIso  MicLib     ;
  ::: LINKED_LIST TrackingS  TrackingF        ;
  ::: SEQ_BINARY  IntlineS   IntlineF         ;    ;
*----
*  Read input information
*----
```

```
REAL     RefPower Puissance MaxBurn ;
INTEGER  NbEtapes  ;
::  >>RefPower<< >>Puissance<< >>MaxBurn<< >>NbEtapes<< ;
ECHO "EvoG2Pui: Specific power per fuel bundle = " Puissance "kW/kg"  ;
ECHO "EvoG2Pui: Maximum burnup                 = " MaxBurn  "kW*J/kg"  ;
ECHO "EvoG2Pui: Number of burnup steps         = " NbEtapes   ;
*----
*  Define modules, data structures and variables
*----
MODULE       SHI: ASM: FLU: EDI: EVO: CPO:
             UTL: BACKUP: DELETE: END:           ;
LINKED_LIST  TmpMicLib PIJ Flux  ;
INTEGER      FinEvo  := 0  ;
*----
*  Variables for Burnup (burnup times) :
*  1) t(1)=0 day
*  2) t(2)=1 day
*  3) t(i)=FacTLog**(i-2) days
*  with FacTLog=exp(ln(MaxBurn/Puissance)/(NbEtapes-2))
*  4) t(NbEtapes)=MaxBurn/Puissance days
*----
REAL         Timei Timef := 0.0 RefPower  Puissance   /  ;
REAL         FacTLog :=
             MaxBurn RefPower / LN NbEtapes 2 - I_TO_R / EXP ;
*----
*  Variables for directory names in the Edition data structure
*----
STRING       RefDir ModDir           ;
*----
*  First flux calculation
*----
TmpMicLib := MicLib ;
INTEGER  NumEtape := 1 ;
EVALUATE RefDir := "Nominal    " NumEtape I_TO_S +               ;
EVALUATE ModDir := "Reflect    " NumEtape I_TO_S +               ;
TmpMicLib := SHI: TmpMicLib TrackingS IntlineS   :: EDIT 0   ;
```

```
PIJ  := ASM: TmpMicLib TrackingF IntlineF        :: EDIT 0   ;
Flux := FLU: PIJ TmpMicLib TrackingF             :: TYPE B B1 PNL ;
PIJ := DELETE:  PIJ ;
EditDS := EDI: Flux TmpMicLib TrackingF          ::
  COND 0.625 MERG COMP
  MICR ALL SAVE ON <<RefDir>>         ;
EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
  COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
  MICR ALL SAVE ON <<ModDir>>         ;
*----------
*  Save also fluxes in EditDS
*----------
EditDS := UTL: EditDS ::
  STEP UP <<RefDir>> STEP UP FluxMultigrp ;
EditDS := BACKUP: EditDS Flux ;
EditDS := UTL: EditDS ::
  STEP DOWN  STEP DOWN ;
*----------
*  Burnup loop
*----------
WHILE NbEtapes NumEtape  > DO
  IF NumEtape 1 = THEN
    ConcIso TmpMicLib := EVO:         TmpMicLib Flux TrackingF ::
      DEPL <<Timei>> <<Timef>> DAY POWR <<Puissance>> ;
  ELSE
    ConcIso TmpMicLib := EVO: ConcIso TmpMicLib Flux TrackingF ::
      DEPL <<Timei>> <<Timef>>   DAY POWR <<Puissance>> ;
  ENDIF ;
  EVALUATE  NumEtape := NumEtape 1 + ;
  IF NumEtape 10 < THEN
    EVALUATE  RefDir := "Nominal    " NumEtape I_TO_S +              ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  RefDir := "Nominal   "  NumEtape I_TO_S +              ;
  ELSE
    EVALUATE  RefDir := "Nominal  "   NumEtape I_TO_S +              ;
  ENDIF ;
```

```
  IF NumEtape 10 < THEN
    EVALUATE  ModDir := "Reflect    " NumEtape I_TO_S +               ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  ModDir := "Reflect   "  NumEtape I_TO_S +               ;
  ELSE
    EVALUATE  ModDir := "Reflect  "   NumEtape I_TO_S +               ;
  ENDIF ;
  TmpMicLib := SHI: TmpMicLib TrackingS IntlineS     :: EDIT 0   ;
  PIJ    := ASM: TmpMicLib TrackingF IntlineF     :: EDIT 0   ;
  Flux   := FLU: Flux PIJ TmpMicLib TrackingF  :: TYPE B B1 PNL  ;
  PIJ := DELETE:  PIJ ;
  EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
    COND 0.625 MERG COMP
    MICR ALL SAVE ON <<RefDir>>          ;
  EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
    COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
    MICR ALL SAVE ON <<ModDir>>          ;
  EditDS := UTL: EditDS ::
    STEP UP <<RefDir>> STEP UP FluxMultigrp ;
  EditDS := BACKUP: EditDS Flux ;
  EditDS := UTL: EditDS ::
    STEP DOWN  STEP DOWN ;
*----
*  Next time step
*  Timei=Timef
*  Timef=Timesi*FacTLog
*----
  EVALUATE Timei  := Timef ;
  EVALUATE Timef  := Timei FacTLog * ;
ENDWHILE ;
*----
*  Clean up
*----
Flux TmpMicLib := DELETE: Flux TmpMicLib ;
QUIT .
```

C.2.4 Procedure EvoG2Ref.c2m

```
 *DECK EvoG2Ref.c2m
*----
*  Nom           : EvoG2Ref.c2m
*  Type          : DRAGON procedure
*  Usage         : Solve transport equation and burn the fuel.
*                  Generate Edition and Burnup data structure.
*  Auteur        : G. Marleau
*         P. Adouki (Summer 2011)
*  Description de la procedure:
*
*  EditDS ConcIso := EvoG2Ref MicLib TrackingS TrackingF
*                                    IntlineS  IntlineF ::
*    <<Puissance>> <<MaxBurn>> <<NbEtapes>>  ;
*  Input structures :
*    MicLib        : Microlib
*    TrackingS     : tracking data structures for self-shielding.
*    TrackingF     : tracking data structures for flux calculations.
*    IntlineS      : Integration lines for self-shielding.
*    IntlineF      : Integration lines  for flux calculations.
*  Input variables :
*    Puissance     : Burnup power.
*    MaxBurn       : Maximum burnup.
*    NbEtapes      : Number of burnup steps.
*  Output structures :
*    EditDS        : Reference Edition data structure.
*    ConcIso       : Burnup data structure.
*
*----
* Definition of the data structures for the procedure.
*----
PARAMETER    EditDS ConcIso MicLib
             TrackingS TrackingF IntlineS IntlineF ::
  ::: XSM_FILE    EditDS  ConcIso  MicLib     ;
  ::: LINKED_LIST TrackingS  TrackingF        ;
  ::: SEQ_BINARY  IntlineS   IntlineF         ;    ;
```

```
*----
*  Read input information
*----
REAL     Puissance MaxBurn ;
INTEGER  NbEtapes  ;
::  >>Puissance<< >>MaxBurn<< >>NbEtapes<< ;
ECHO "EvoG2Ref: Specific power per fuel bundle = " Puissance "kW/kg"  ;
ECHO "EvoG2Ref: Maximum burnup                 = " MaxBurn  "kW*J/kg"  ;
ECHO "EvoG2Ref: Number of burnup steps         = " NbEtapes   ;
*----
*  Define modules, data structures and variables
*----
MODULE       SHI: ASM: FLU: EDI: EVO: CPO:
             UTL: BACKUP: DELETE: END:           ;
LINKED_LIST  TmpMicLib PIJ Flux  ;
*----
*  Variables for Burnup (burnup times) :
*  1) t(1)=0 day
*  2) t(2)=1 day
*  3) t(i)=FacTLog**(i-2) days
*  with FacTLog=exp(ln(MaxBurn/Puissance)/(NbEtapes-2))
*  4) t(NbEtapes)=MaxBurn/Puissance days
*----
INTEGER      FinEvo  := 0  ;
REAL         Timei Timef := 0.0 1.0       ;
REAL         FacTLog :=
             MaxBurn Puissance / LN NbEtapes 2 - I_TO_R / EXP ;
*----
*  Variables for directory names in the Edition data structure
*----
STRING       RefDir ModDir  ;
*----
*  First flux calculation
*----
TmpMicLib := MicLib ;
INTEGER  NumEtape := 1 ;
```

```
EVALUATE RefDir := "Nominal    " NumEtape I_TO_S +               ;
EVALUATE ModDir := "Reflect    " NumEtape I_TO_S +               ;
TmpMicLib := SHI: TmpMicLib TrackingS IntlineS   :: EDIT 0   ;
PIJ  := ASM: TmpMicLib TrackingF IntlineF        :: EDIT 0   ;
Flux := FLU: PIJ TmpMicLib TrackingF             :: TYPE B B1 PNL ;
PIJ := DELETE:  PIJ ;
EditDS := EDI: Flux TmpMicLib TrackingF          ::
  COND 0.625 MERG COMP
  MICR ALL SAVE ON <<RefDir>>         ;
 EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
  COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
  MICR ALL SAVE ON <<ModDir>>         ;
*----------
*  Save also fluxes in EditDS
*----------
EditDS := UTL: EditDS ::
  STEP UP <<RefDir>> STEP UP FluxMultigrp ;
EditDS := BACKUP: EditDS Flux ;
EditDS := UTL: EditDS ::
  STEP DOWN  STEP DOWN ;
*----------
*  Burnup loop
*----------
WHILE NbEtapes NumEtape  > DO
  IF NumEtape 1 = THEN
    ConcIso TmpMicLib := EVO:         TmpMicLib Flux TrackingF ::
      DEPL <<Timei>> <<Timef>> DAY POWR <<Puissance>> ;
  ELSE
    ConcIso TmpMicLib := EVO: ConcIso TmpMicLib Flux TrackingF ::
      DEPL <<Timei>> <<Timef>>   DAY POWR <<Puissance>> ;
  ENDIF ;
  EVALUATE  NumEtape := NumEtape 1 + ;
  IF NumEtape 10 < THEN
    EVALUATE  RefDir := "Nominal    " NumEtape I_TO_S +               ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  RefDir := "Nominal   "  NumEtape I_TO_S +               ;
```

```
  ELSE
    EVALUATE  RefDir := "Nominal  "   NumEtape I_TO_S +               ;
  ENDIF ;
  IF NumEtape 10 < THEN
    EVALUATE  ModDir := "Reflect    " NumEtape I_TO_S +               ;
  ELSEIF NumEtape 100 < THEN
    EVALUATE  ModDir := "Reflect   "  NumEtape I_TO_S +               ;
  ELSE
    EVALUATE  ModDir := "Reflect  "   NumEtape I_TO_S +               ;
  ENDIF ;
  TmpMicLib := SHI: TmpMicLib TrackingS IntlineS     :: EDIT 0   ;
  PIJ    := ASM: TmpMicLib TrackingF IntlineF     :: EDIT 0   ;
  Flux   := FLU: Flux PIJ TmpMicLib TrackingF  :: TYPE B B1 PNL  ;
  PIJ := DELETE:  PIJ ;
  EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
    COND 0.625 MERG COMP
    MICR ALL SAVE ON <<RefDir>>          ;
  EditDS := EDI: EditDS Flux TmpMicLib TrackingF          ::
    COND 0.625 MERG MIX 0 0 0 0 0 0 0 1
    MICR ALL SAVE ON <<ModDir>>          ;
  EditDS := UTL: EditDS ::
    STEP UP <<RefDir>> STEP UP FluxMultigrp ;
  EditDS := BACKUP: EditDS Flux ;
  EditDS := UTL: EditDS ::
    STEP DOWN  STEP DOWN ;
*----
*  Next time step
*  Timei=Timef
*  Timef=Timesi*FacTLog
*----
  EVALUATE Timei  := Timef ;
  EVALUATE Timef  := Timei FacTLog * ;
ENDWHILE ;
*----
*  Clean up
*----
```

```
Flux TmpMicLib := DELETE: Flux TmpMicLib ;
QUIT "LIST" .
```

C.2.5 Procedure GEOG2.c2m

```
 *****************GEOG2.c2m*****************************************
**************Modified version of SCWRGeo2D.c2m of G. Harrisson*****
**************Modifications by P. Adouki (Summer 2011)**************
PARAMETER          Tracking  Intline ::
    ::: LINKED_LIST Tracking     ;
    ::: SEQ_BINARY  Intline      ;    ;
STRING  Option ;
:: >>Option<<          ;

*----
*  Local modules used in this procedure
*----
MODULE       GEO: NXT: DELETE:                        ;
*----

*----
*  Local data structures used in this procedure
*----
LINKED_LIST  LocalGeo                                  ;
*----

*----
*  Select geometry
*----
LocalGeo := GEO: :: CARCEL 8 3 3
   EDIT 0
   X- REFL MESHX -12.5 -8.4853 8.4853 12.5 X+ REFL
   Y- REFL MESHY -12.5 -8.4853 8.4853 12.5 Y+ REFL
   RADIUS  0.00000  2.10480  3.60300  5.06525  6.80000  6.90000
           8.23000  9.63000  12.00000
   MIX     1 1 1 1 3 6 7 8 8
           1 1 1 1 3 6 7 8 8
```

```
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
            1 1 1 1 3 6 7 8 8
   CLUSTER ROD1 ROD2 ROD3 ROD4
      ::: ROD1 := GEO: TUBE 2
           RADIUS 0.000 1.800 2.000
           MIX  28 29
           NPIN  1 RPIN 0.0000 APIN 0.0000 ;
      ::: ROD2 := GEO: TUBE 2 1 2
           RADIUS 0.000 0.620 0.660
           MESHX -0.660       0.660
           MESHY -0.660 0.000 0.660
           MIX 12 9 15 9
           NPIN  12 RPIN 2.8755  APIN 0.2618 ;
      ::: ROD3 := GEO: TUBE 2 1 2
           RADIUS 0.000 0.620 0.660
           MESHX -0.660       0.660
           MESHY -0.660 0.000 0.660
           MIX 18 9 21 9
           NPIN 18 RPIN 4.3305  APIN 0.1745 ;
      ::: ROD4 := GEO: TUBE 2 1 2
            RADIUS 0.000 0.620 0.660
            MESHX -0.660       0.660
            MESHY -0.660 0.000 0.660
            MIX 24 9 27 9
            NPIN 24 RPIN 5.8000  APIN 0.1309 ; ;

IF Option "Flux" = THEN
   LocalGeo := GEO: LocalGeo :: SPLITR 1 21 21 21 1 14 3 7
                              SPLITX 4 1 4
                              SPLITY 4 1 4
   ::: ROD1 := GEO: ROD1 SPLITR 1 1 ;
```

```
   ::: ROD2 := GEO: ROD2 SPLITR 4 1 ;
   ::: ROD3 := GEO: ROD3 SPLITR 4 1 ;
   ::: ROD4 := GEO: ROD4 SPLITR 4 1 ; ;
ENDIF ;

*----
*  Process the geometry
*----
IF Option "Flux" = THEN
 Intline Tracking := NXT: LocalGeo :: EDIT 10 TISO 20 20.0 ;
ELSE
 Intline Tracking := NXT: LocalGeo :: EDIT 10 TISO 20 35.0 ;
ENDIF ;
*----
*  Clean up
*----
LocalGeo := DELETE:  LocalGeo                                  ;
QUIT "LIST" .
```

C.2.6 Procedure MicG2IAEA.c2m

```
**********************MicG2IAEA.c2m************************************
**********Modified version of SCWRLib.c2m of G. Harrisson*************
**************Modifications by P. Adouki (Summer 2011)****************
*
*Description de la procedure:
*BiblioInt := SCWRLib :: <<TCalo>> <<DCalo>> <<DCaloIsol>> ;
*TCalo     : Temperature du caloporteur en K
*DCalo     : Densite du caloporteur en g/cm3
*DCaloIsol : Densite du caloporteur a la temperature de l'isolant en g/cm3
*BiblioInt : Bibliotheque interne requise pour les calculs
*
*-----------------------------------------------------------------------
*Definir les structures de donnees des parametres et les modules utilises
*-----------------------------------------------------------------------
PARAMETER  BiblioInt :: ::: XSM_FILE BiblioInt ; ;
MODULE  INFO: LIB: DELETE: END: ;
```

```
*----------------------------------------
*Lire les variables transmises a la procedure
*----------------------------------------
REAL  DCaloIsol  TComb  TCalo  TMode
      DCalo      DMode  PCalo  PMode
      Bore       Xe     Sm     Np     ;

:: >>TComb<< >>TCalo<< >>TMode<<
   >>DCalo<< >>DMode<<
   >>PCalo<< >>PMode<<
   >>Bore<< >>Xe<< >>Sm<< >>Np<<
   >>DCaloIsol<<
   ;
REAL BNatMode := 1.0E-10 ;
*----------------------------
*Definir les variables locales
*----------------------------
REAL TLiner     TTubFrc    TGaine      TIsol
     WgtH1Calo  WgtD2Calo  WgtO16Calo
     WgtH1Mod   WgtD2Mod   WgtO16Mod ;
*----------------------------------------------------
*Definir la temperature des melanges a partir de TCalo
*----------------------------------------------------
EVALUATE TLiner  := TCalo ;
EVALUATE TTubFrc := 0.3324 TCalo * 267.36 + ;
EVALUATE TGaine  := 0.4989 TCalo * 480.87 + ;
EVALUATE TIsol   := 0.666  TCalo * 133.73 + ;

*-----------------------------------------------------------------------------
*Composition isotopique (en % massique) de l'eau du calcoporteur et du moderateur
*-----------------------------------------------------------------------------
INFO: ::
  PUR: <<PCalo>>   ATM%
  LIB: WIMSD4 FIL: endfb7
  ISO: 3 '3001'   '3002'   '6016'
  CALC WGT% D2O >>WgtH1Calo<< >>WgtD2Calo<< >>WgtO16Calo<< ;
```

```
INFO: ::
  PUR: <<PMode>>   ATM%
  LIB: WIMSD4 FIL: endfb7
  ISO: 3 '3001'   '3002'   '6016'
  CALC WGT% D2O >>WgtH1Mod<< >>WgtD2Mod<< >>WgtO16Mod<< ;
*-------------------------
*Donnees IAEA - ENDF/B-VII
*-------------------------
BiblioInt := LIB: ::
  EDIT 0
  NMIX 29 CTRA WIMS
  DEPL LIB: WIMSD4 FIL: endfb7
  MIXS LIB: WIMSD4 FIL: endfb7
*---------------------------------
*Definir les melanges de la cellule
*---------------------------------
*CALOPORTEUR (Eau legere : 99.984 %ATM H2O & 0.0156 %ATM D2O)
*-------------------------------------------------------------
  MIX  1  <<TCalo>>   <<DCalo>>
    CH1  = '3001'  <<WgtH1Calo>>
    CD2  = '3002'  <<WgtD2Calo>>
    CO16 = '6016'  <<WgtO16Calo>>

*LINER (30 % Acier inoxydable 310 et 70 % Caloporteur)
*-----------------------------------------------------
  MIX  2  <<TLiner>>  7.75
    C    = '2012'   0.250
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433

  MIX 3 COMB 2 0.30 1 0.70
```

```
*ISOLANT (30 % ZrO2 et 70 % Caloporteur)
*---------------------------------------
  MIX 4  <<TIsol>>  5.68
    Zr   = '91'    100.0026
    O16  = '6016'   35.0684

  MIX 5  <<TIsol>>  <<DCaloIsol>>
    CH1  = '3001'  <<WgtH1Calo>>
    CD2  = '3002'  <<WgtD2Calo>>
    CO16 = '6016'  <<WgtO16Calo>>

  MIX 6 COMB 4 0.30 5 0.70

*TUBE DE FORCE (Alliage de Zr : Zr-2.5Nb)
*----------------------------------------
  MIX 7  <<TTubFrc>>  6.515
    Nb93 = '93'  2.58
    Fe   = '2056'   0.046780177764
    Cr   = '52'     0.008087975736
    Ni   = '58'     0.0035
    B10  = '1010'   0.00002431
    Zr   = '91'    97.3132811882

*MODERATEUR (Eau lourde : 99.833 %ATM D2O & 0.167 %ATM H2O)
*---------------------------------------------------------
  MIX  8  <<TMode>>  <<DMode>>
    MH1  = '3001'  <<WgtH1Mod>>
    MD2  = '3002'  <<WgtD2Mod>>
    MO16 = '6016'  <<WgtO16Mod>>
    MB10 = '1011' <<BNatMode>>

*GAINE (Acier inoxydable 310)
*---------------------------
  MIX 9    <<TGaine>>  7.75
    C    = '2012'   0.250
```

```
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433

*COMBUSTIBLE 1 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
MIX  10  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     1
    Pu239 = '6239'  54.2     1
    Pu240 = '1240'  23.8     1
    Pu241 = '1241'  12.6     1
    Pu242 = '242'    6.8     1

  MIX 11  <<TComb>>  9.70
    Th232 = '2232'  100.0    1
    Pa233 = '1233'    0.0    1
    U233  = '9233'    0.0    1
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 12 COMB 10 0.12 11 0.88


*COMBUSTIBLE 2 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
MIX  13  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     2
```

```
    Pu239 = '6239'  54.2     2
    Pu240 = '1240'  23.8     2
    Pu241 = '1241'  12.6     2
    Pu242 = '242'    6.8     2

  MIX 14  <<TComb>>  9.70
    Th232 = '2232'  100.0    2
    Pa233 = '1233'    0.0    2
    U233  = '9233'    0.0    2
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 15 COMB 13 0.12 14 0.88

*COMBUSTIBLE 3 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
 MIX  16  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     3
    Pu239 = '6239'  54.2     3
    Pu240 = '1240'  23.8     3
    Pu241 = '1241'  12.6     3
    Pu242 = '242'    6.8     3

  MIX 17  <<TComb>>  9.70
    Th232 = '2232'  100.0    3
    Pa233 = '1233'    0.0    3
    U233  = '9233'    0.0    3
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 18 COMB 16 0.12 17 0.88
```

```
*COMBUSTIBLE 4 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
  MIX  19  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     4
    Pu239 = '6239'  54.2     4
    Pu240 = '1240'  23.8     4
    Pu241 = '1241'  12.6     4
    Pu242 = '242'    6.8     4

  MIX 20  <<TComb>>  9.70
    Th232 = '2232'  100.0    4
    Pa233 = '1233'    0.0    4
    U233  = '9233'    0.0    4
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 21 COMB 19 0.12 20 0.88

*COMBUSTIBLE 5 (90% Thorium et 10% Plutonium recycle)
*-------------------------------------------------
   MIX  22  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     5
    Pu239 = '6239'  54.2     5
    Pu240 = '1240'  23.8     5
    Pu241 = '1241'  12.6     5
    Pu242 = '242'    6.8     5

  MIX 23  <<TComb>>  9.70
    Th232 = '2232'  100.0    5
    Pa233 = '1233'    0.0    5
    U233  = '9233'    0.0    5
```

```
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 24 COMB 22 0.12 23 0.88

*COMBUSTIBLE 6 (90% Thorium et 10% Plutonium recycle)
*----------------------------------------------------
  MIX  25  <<TComb>>  9.70
    O16   = '6016'  13.389
    Np239 = '1939'   <<Np>>
    Pu238 = '948'    2.5     6
    Pu239 = '6239'  54.2     6
    Pu240 = '1240'  23.8     6
    Pu241 = '1241'  12.6     6
    Pu242 = '242'    6.8     6

  MIX 26  <<TComb>>  9.70
    Th232 = '2232'  100.0    6
    Pa233 = '1233'    0.0    6
    U233  = '9233'    0.0    6
    O16   = '6016'   13.79
    Sm149 = '4149'   <<Sm>>
    Xe135 = '4135'   <<Xe>>

  MIX 27 COMB 25 0.12 26 0.88

*PIN CENTRALE (Eau legere : 99.984 %ATM H2O & 0.0156 %ATM D2O)
*------------------------------------------------------------
  MIX  28  <<TCalo>>   <<DCalo>>
    H1  = '3001'  <<WgtH1Calo>>
    D2  = '3002'  <<WgtD2Calo>>
    O16 = '6016'  <<WgtO16Calo>>

*GAINE PIN CENTRALE (Acier inoxydable 310)
*----------------------------------------
```

```
  MIX 29    <<TGaine>>  7.75
    C    = '2012'   0.250
    Si   = '29'     1.499999
    P31  = '31'     0.045
    S    = '32'     0.029999
    Mn55 = '55'     2.000
    Cr   = '52'    25.000015
    Fe   = '2056'  50.675132581
    Ni   = '58'    19.956433 ;

END: ;
QUIT "LIST" .
```